10/p.

N63 18161

Code-1

# TECHNICAL NOTE

D-1830

## THE SIGNIFICANCE OF ATMOSPHERIC BALLISTICS IN ROCKET TECHNOLOGY

By G. H. R. Reisig

George C. Marshall Space Flight Center
Huntsville, Alabama

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON July 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1830

# THE SIGNIFICANCE OF ATMOSPHERIC EFFECTS IN ROCKET VEHICLE TECHNOLOGY

By

G. H. R. Reisig

TEST DIVISION

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

## LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1830

# THE SIGNIFICANCE OF ATMOSPHERIC EFFECTS IN ROCKET VEHICLE TECHNOLOGY

by G. H. R. Reisig

## SUMMARY

18161 over

The physical properties of the atmosphere pertain to the basic elements of rocket ballistics. The influence of these atmospheric properties on both rocket design and performance are grouped under three topics, namely.

a. Rocket design climatology

b. Atmospheric rocket physics

c. Atmospheric environments for rocket firings.

"Rocket design climatology" provides the rocket designer with quantitative design criteria in terms of global climatological parameter values at discrete probability levels of occurrence. These atmospheric parameters include climatological "profiles" (as a function of altitude) of wind speed, wind shear, atmospheric turbulence, density, pressure, temperature, hydrometeors, and atmospheric radiation. The physical relations of these atmospheric quantities to aeroballistic parameters of rocket design are discussed, and include such aerodynamic quantities as dynamic pressure, drag, lift, axial and normal forces, moments, angle-of-attack; also flowscale parameters as Mach number, Reynolds number, Prandtl number, etc. A status report on the establishment of a station-wise aerological climatology is given.

The topics in "Atmospheric rocket physics" pertain to the mechanics of reaction of the rocket shell and its interior members to particular atmospheric phenomena encountered along the rocket flight path. Also, the mechanics of complex atmospheric features like free-flow turbulence, collection and

18(C(

impingement of hydrometeors at both sub- and supersonic-flight speeds, atmospheric-aerodynamic heating processes, and rarefied gas effects are explored with regard to rocket flight. The urgency of atmospheric measurements in the "Ignosphere" between 30 and 100 km altitude is stressed.

The area of "Atmospheric environments for rocket firings" is concerned with the atmospheric criteria for both flight performance and flight safety of rocket firings. Aerological climatologies have to be applied with trajectory programming and preflight rocket stability analysis. The atmospheric data for the post-flight analysis of the overall rocket performance have to be provided by meteorological observatories on the rocket firing ranges. The pertaining problem of atmospheric data acquisition and high altitude instrumentation is discussed, emphasizing its primary significance in aerology for rocket flight purposes.

## I. INTRODUCTION

If a body is propelled through a medium, the physical properties of this medium have to be known in order to determine or predict the motion or the path of the propelled body. These physical properties not only comprise the "static" parameters of the medium, like pressure, temperature, or density, but also its dynamic parameters, describing the eventual motions of the medium itself, or its "currents". This statement holds true for an airplane flying in the relatively low regions of the atmosphere, for a torpedo traveling through the water, as well as for a rocket being fired through large depths of the atmosphere. The probability that a torpedo would score a hit would be slight if the man, firing the torpedo, overlooked the existence of a substantial water current between his ship and the target ship.

In the case of rockets, the properties of the atmosphere have to be studied and understood to determine their impact on the flight mechanical, structural, and, generally, ballistic behavior of the fired rocket along its trajectory through the atmosphere. The naive arguer contends that the rockets travel too fast to be influenced by the atmosphere. As a matter of fact, the faster a vehicle travels the more severe will be the external atmospheric disturbance. This will be explained later in this paper. The second argument maintains that since lift forces are hardly effective in rocket aerodynamics, other aerodynamic forces would not be effective either. Drag forces, however, represent a substantial problem in rocket ballistics, and considerable effort has to be made in the stability-control and guidance area to overcome lateral aerodynamic forces and moments. Atmospheric effects on rocket shells constitute an essential part of rocket ballistics, and should be thoroughly considered and analyzed.

For approximately ten years, atmospheric problems have been dealt with in the various rocket development activities (Reisig, Reference 1). This work originated new concepts in meteorology, particularly in climatology. The conventional climatology of meteorological agencies was primarily concerned with climatological phenomena at the surface of the earth. The rocket developer, however, needs to know the climatological features of the atmosphere in the vertical direction, throughout the troposphere up to high altitudes in the stratosphere (Figure 1). In the meantime, rocket developers established the basis for an extensive aerological climatology (Alfuth and Smith, Reference 2), suited to rocket design and flight performance purposes.

Furthermore, new concepts of atmospheric physics were developed, particularly from rocket ballistics which do not exist in conventional climatology. Primarily, atmospheric density does not exist as a common atmospheric parameter in conventional meteorology, although it is of eminent importance to rocket ballistics. Any time the rocket designer requests from meteorologists density information either on the surface or in the free atmosphere, these data have to be specifically computed at the expense of the rocket developing agency.

Another very important atmospheric parameter which does not exist in terms of climatology is the vertical wind shear. With its many modifications and specifications for ballistic purposes, the vertical wind shear concept was developed by the rocket ballisticians as a concisely defined atmospheric quantity. From studies of flight mechanical conditions of rockets in nonstationary airflow, rocket ballisticians found that conventional meteorology does not provide a clear definition of the general wind profile which is necessary for an unequivocal derivation of the vertical wind shear (Reiter, Reference 3). The first statistical compilation of vertical wind-shear data of the free atmosphere in existence was accomplished for the Atlantic Missile Range (Patrick Air Force Base, Florida).

A very great handicap exists if conventional meteorological information is used in rocket design work because meteorologists have abandoned the concept of "altitude". Meteorologists treat upper atmospheric data as a function of pressure surfaces because this is more convenient for synoptical work and numerical forecasting. Figure 2 indicates that the surfaces of constant pressure vary their altitudes with the particular weather situation. This "ill-famed phenomenon" is well known in aviation, since the barometric-type altimeter in the airplane has to be consistently reset according to the surface pressure during flight in the prevailing weather situation (Roessger and Raenicke, Reference 4). It is quite obvious that the rocket ballistician does not at all care for the synoptic altitude location of a certain pressure surface. For his ballistic problems, he must know the pressure that is to be met at a definite altitude of the rocket trajectory. But the meteorologist can no longer provide this information from his routine data, and specifically, it has to be prepared at the expense of the requesting rocket developing agency.

Summarizing, it is concluded that the rocket developing agency has more than just good reason for extensive investigations in all pertinent areas of atmospheric effects on rocket ballistics, and into their quantitative background. This is required for the following reasons:

a. To formulate and clearly understand the physical processes occurring in the atmosphere which affect the rocket on its trajectory.

b. To translate the atmospheric effects on rockets in the proper meteorological terms to convey the rocket designer's needs to the meteorologist.

c. To interpret meteorological facts into terms of rocket ballistics for the benefit of the rocket designer.

d. To establish definite atmospheric conditions for rocket firings.

## II. ATMOSPHERIC ROCKET BALLISTICS

The field of atmospheric rocket ballistics can be organized conveniently within three major areas, namely (Table I):

a. Rocket design climatology.

b. Atmospheric rocket physics.

c. Atmospheric environments for rocket firings.

In general, the first area, rocket design climatology, is devoted to providing the rocket designer (which includes the rocket ballistician) with quantitative design criteria. These parametric criteria represent the input data for a certain rocket design to meet the atmospheric conditions prevailing along its projected trajectory, both with regard to the structural strength of the rocket shell and the control and guidance stability of the rocket.

The general topic for the second area, "Atmospheric Rocket Physics", consists of the analysis of the specific reactions of the rocket shell and its interior components to the particular atmospheric phenomena to be encountered by the rocket along its trajectory. The physical interactions between the rocket and its medium of propagation, the atmosphere, have to be analyzed in mathematical terms. The goal of these mathematical derivations is the establishment of the atmospheric "perturbation functions" as the input for any kind of rocket stability analysis. All of these developed analytical methods provide the tool for the rocket designer to treat the atmospheric interference on the rocket in proper quantitative form.

Finally, the third area, "Atmospheric Environments for Rocket Firings", is concerned with providing the atmospheric criteria for the rocket firings at any selected launching site. Proper atmospheric information is needed for the programming and scheduling of rocket firings, and for the prediction of rocket flight performance. The control of rocket flight safety has to be maintained with regard to prevailing atmospheric conditions. Furthermore, the atmospheric data for the post-flight analysis of the rocket performance have to be collected.

## A. TOPICS IN ROCKET DESIGN CLIMATOLOGY

The topics of rocket design climatology may be represented by eight branches of aerological climatology which are (Table II):

a. Wind climatology.

b. Wind shear climatology.

c. Turbulence and gustiness climatology.

d. Density climatology.

e. Pressure climatology.

f. Temperature climatology.

g. Hydrometeor climatology.

h. Radiation climatology.

In particular, the following should be explained about these specific branches of rocket design climatology:

1. Wind Climatology. The wind is one of the two principal inputs into rocket ballistics, the other being density. Before any further discussion of the ballistic wind effects, the wind and its associated terms should be clarified in order to eliminate the usual confusion about characteristic wind features. Figure 3 shows an idealized profile of the windspeed - on the abscissa - versus altitude - on the ordinate. The light zigzag trace indicates the actual or instantaneous windspeed, measured with instrumentation of sufficient resolving power. The heavy solid trace represents the average windspeed which persists for a longer time period, preferably for a few minutes up to several hours. The meteorologists are particularly interested in this average windspeed profile for analyzing and forecasting the weather. Therefore, this average windspeed has been designated "synoptic wind" in terms of atmospheric ballistics.

The wind shear is defined as the change of windspeed of the average windspeed profile with an increment of altitude:

$$WS = \Delta w / \Delta h.$$

The emphasis in this definition lies on "average" windspeed, which means, the wind shear represents the rate of change of windspeed which significantly contributes to the "buildup" of the average wind profile. Imagine that the average windspeed profile is constructed from a minimum number of consecutive "windshear triangles" with hypotenuses as large as feasible. This windshear definition is of the greatest significance to the analysis of rocket ballistics in general, and of stability problems in particular. In contrast to this windshear concept, the slope of the actual zigzag windspeed curve has been termed "wind gradient", indicating the instantaneous derivative of the windspeed with altitude. The slopes of these short-time wind fluctuations do not contribute to the buildup of the average windspeed profile. The resultant of the wind gradients, summed up over a proper altitude interval, approximates zero because of the alternating positive and negative amplitudes of the short-time windspeed fluctuations (Essenwanger, Reference 5, page 8).

With these definitions of the windspeed profile in mind, the effects of the windspeed on rocket ballistics are concerned with (Table III):

a. Angle of attack, which affects rocket stability, rocket path, and the structural strength of the rocket.

b. Attitude angle of rocket axis, as related to angle of attack.

c. Lateral acceleration of rocket center of gravity.

d. Dynamic pressure, which enters into practically every aerodynamic quantity like lift, drag, moment, etc.

e. Mach number, which is a very influential parameter in high speed flight.

f. Reynolds number, which is of particular concern with drag and heat transfer problems in the boundary layer of the rocket shell.

Any climatology for the purpose of rocket design should be of global significance because the usability of any rocket type should be independent of the geographic location of the launching site. The only global windspeed climatology available so far is one derived from 12 stations in the northern hemisphere (Figure 4; Reisig, Reference 6).

The slightly idealized curves of Figure 4 show the scalar windspeeds which will not be exceeded for the indicated percentage level of probability or frequency of occurrence. For instance, at the 50 percent level, which approximately represents the average case, the global windspeed will not be higher than 15 meters per second at any altitude, or only in one-tenth of one percent of the cases, will the windspeed be higher than 94 meters per second at any altitude level. In terms of rocket ballistics, these percentile windspeed limits mean the following: If the structural strength of a rocket shell were laid out for a wind speed of 94 meters per second, only one rocket out of 1000 would be likely to have structural failure because of potential higher wind speeds.

The windspeed climatology shown in Figure 4 was established in April 1958 and should be revised on a true global scale, as soon as possible for better reliability of the rocket design criteria. The scientifically, well-analyzed material of 47 global stations is on hand, and more stations are currently being obtained (Table IV A and B).

The frequency distributions of wind speed in Figure 4 contain the true magnitudes of all wind speeds occurring in any possible wind direction. Therefore, these wind values are termed the "scalar" wind speeds. They represent the "worst possible condition" for rocket application. Applying these windspeed probabilities to any specific rocket flight mission would exaggerate the actual wind influence on the specific rocket performance. This results from the fact that each ballistic rocket trajectory stays in a predetermined flight plane direction which not necessarily coincides with the prevailing instantaneous wind direction at any flight altitude. Rather, only a component of the true wind speed will generally be projected into the preselected flight plane, thus reducing the windspeed acting on the rocket shell in the direction of a particular rocket reference axis.

For an illustration of this wind situation with respect to ballistic effects on the rocket, Figure 5 represents the mean windspeed in the north-south plane ("meridional" windspeed) at Cape Canaveral, Florida, during December (Smith and Vaughan, Reference 7). A north-south flight plane of the rocket is assumed for this case. The average windspeed in the north-south flight plane is almost zero during December, except for windspeeds below two meters per second in the lowest five kilometer altitude range (solid line in Figure 5). For comparison, the scalar windspeeds have been included in Figure 5 (dashed line), which increase up to almost 40 meters per second (at 13 km altitude) at the same location and during the same month. It is quite evident how much the wind effects in direction of the longitudinal axis of the rocket would be overestimated if the scalar windspeeds would be applied for a north-south flight plane direction.

However, the average windspeed components in the flight plane direction (average meridional windspeeds) still do not give the most realistic wind information to be applied for the selected rocket flight direction. In the average windspeed profile for a particular plane, windspeed components of opposite direction are lumped together for the statistical evaluation. Hence, the average meridional wind speed of zero in Figure 5 could be fictitious if opposite windspeeds with closely equal magnitudes would occur at a certain altitude level with about equal frequencies. Then "head winds" and "tail winds" (with respect to the chosen rocket flight plane) would approximately cancel each other out in the averaging process. That this particular condition is true in the chosen sample case is demonstrated in Figure 6A and Figure 6B. For these two windspeed frequency distributions, the very same wind data populations have been used for the profiles in Figure 5. However, the cases of northern (Figure 6A) and southern (Figure 6B) windspeed components have been averaged separately in one pertaining profile each. Thus, the actual existence of head and tail winds becomes evident, which are considerably different from zero windspeed. These "semiplanar" windspeed profiles truly represent the most adequate wind profiles applicable to ballistic rocket problems if conventional climatological statistics are used; for instance, classifying wind data according to time periods of seasons or months.

Although the windspeed frequency profiles as shown in Figures 6A and 6B properly represent the features of head and tail winds in a particular rocket flight plane, they still lack considerable reality with respect to the "historical" truthfulness of individual wind profiles. It has to be realized that the statistically derived wind profiles only represent envelopes of windspeeds which will not be exceeded at a certain probability level. These profiles will never be encountered during any particular rocket flight, and thus lack "historical" reality. Actually, it could happen that the true wind situation for a certain missile trajectory may alternate from the "head wind" profile at one flight altitude to the "tail-wind" profile at an adjacent flight altitude. Anyway, the individual features of any "historical" wind profile are lost during the statistical evaluation process. However, the history of atmospheric perturbations along the rocket trajectory is quite essential for the flight mechanical analysis of the rocket stability behavior, and for trajectory perturbations.

Investigations concerned with the climatology of "historical" wind profiles revealed that certain types of windspeed profiles are characteristic for certain typical weather situations prevailing at a selected geographic location (Essenwanger, Reference 8). In particular, it was found that a constant direction of a layer of atmospheric flow just above the surface layer readily characterizes a typical weather situation at a certain location. Figure 7 represents a very instructive sample of this close relation between weather situation and constant flow direction in a low "entrance layer" of a typical wind profile. The sample is taken from the wind data of Washington, D. C. (Silver Hill) (Reference 8). The data pertain to the summer season. The "entrance layer" of constant flow direction extends from 1500 to 3000 meter altitude. The profiles represent the mean wind direction, as a function of altitude, for equal flow direction at the "entrance layer". It appears significant that flow directions in the "entrance layers" from east through south to west are followed by "veering" directional profiles in the troposphere. In contrast, "entrance layers" with wind directions from west through north to east are followed by "backing" directional profiles in the troposphere. In the region of the tropopause, all directional profiles tend toward the eastern flow direction. In the stratosphere up to at least 30 kilometers, an almost unique eastern flow direction is prevailing. This means that the atmospheric conditions in the stratosphere during the summer evidently are independent of the tropospheric weather situations (Faust, Reference 9).

Once the classification of mean wind direction profiles as a function of weather situations has been established by means of the "entrance-level" concept with constant flow direction, the windspeed profiles can be classified accordingly. Figure 8 presents the mean scalar windspeed profiles classified according to the wind direction classes of Figure 7. Although these windspeed profiles exhibit a similar shape for all classes, the actual variation of mean windspeed among these classes is quite substantial. It amounts to a maximum of 16 meters per second at 14 kilometers altitude, which is about 68 percent of the maximum windspeed in any of the mean profiles. Also, the variation of the slopes of many of the typical windspeed profiles should be noticed, whose significance shall be discussed under the topic of wind shear climatology (Section II. A. 2.). Of course, it still has to be investigated which ones of these windspeed classes are significantly different from each other, or whether a consolidation of some adjacent classes would be indicated statistically.

After the classes of typical windspeed profiles have been established by means of characteristic parameters of atmospheric flow direction, a more strictly analytical approach can be rendered toward the windspeed classification. Pertinent investigations by Essenwanger (Reference 10) have already resulted in analytical representations of wind profiles by means of low-degree polynomials. Figure 9 shows, in the left graph, a satisfactory typification of an individual wind direction profile by a five-term polynomial. The right graph presents the close typification of the pertaining windspeed profile by a two-term Fourier series. Applying this analytical method, climatology then proceeds from the statistical treatment of accumulations of sequences of individual numbers in conventional climatology to the climatology of representative functions which will open a new era of aerology.

2. Wind Shear Climatology. In the atmospheric ballistics concept, the wind shear has been defined in Paragraph II. A.1 as the rate of change of the average windspeed with altitude which contributes significantly to the "buildup" of the average windspeed profile.

Ballistic effects of the wind-shear phenomena apply to both flight-mechanical stability problems and structural-strength problems of rocket shells. In particular, the ballistic parameters involved are (Table V):

a. Angle of attack increments.

b. Angular velocity of rocket axes about rocket center of gravity, as related to angular velocity of angle of attack.

c. Change of lateral accelerations.

d. Non-stationary parts of aerodynamic forces and moments, as consequence of items a, b, and c.

Flight mechanical analysis of wind-shear effects on rocket shells proved that the wind-shear magnitudes depend on the height interval selected for the derivation of the wind-shear data. This property of the wind-shear magnitudes was recognized as early as 1952 (Reisig, Reference 1). Therefore, the "Scale of Distance" (SOD) concept was established, which represents the height interval for which a particular wind-shear value is valid (Vaughan, Reference 11). Figure 10 shows the magnitude of the wind shear as a function of Scale of Distance. The parameters for these curves are the probability levels for which the indicated wind-shear magnitudes will not be exceeded. Particularly, for Scales of Distance below 1500 meters, the wind-shear magnitudes increase with a relatively high power. It has to be emphasized again that all wind-shear curves in this graph are derived from one and the same set of raw wind data. An integral discussion of the flight mechanical significance of the Scale of Distance dependency of wind shear is presented in Reference 12.

The first wind-shear climatology ever established is the one for Cape Canaveral, Florida, as shown in Figure 11. The graph presents the annual cumulative frequency-of-occurrence of the wind-shear values of various probability levels, and as a function of altitude. The Scale of Distance was selected to be 1000 meters. Evidently, the largest wind-shear values evolve with increasing cumulative frequency levels at altitudes between the local jet stream level (about 13 kilometers altitude) and the local tropopause (circa 16 kilometers altitude). The relation between rocket characteristics and wind-shear probabilities is similar to the one with wind-speed probabilities. For example, assume a control system designed for rocket attitude stability at wind-shear values up to 99 percent probability of occurrence. Then, only one rocket out of 100 would not be safe against stability failure, with all possible wind-shear values, or 100 percent wind-shear frequency, ever occurring in the particular location under consideration.

Although the wind-shear climatologies of several significant stations are available by now (Table IV A and B), the establishment of a global wind-shear climatology remains to be an urgent need for rocket-design purposes, particularly in the areas of aeroelasticity of rocket shells, and control and guidance systems.

3. <u>Turbulence Climatology</u>. With the progressive refinement of the guidance and control characteristics of modern rocket concepts, the significance of non-stationary air forces of short duration has been recognized. These aerodynamic impacts of short duration are created by atmospheric turbulence, or gustiness. The ballistic impact of atmospheric turbulence is similar to that of wind shear. The turbulence impacts on the rocket shell, however, are of shorter duration, but repeat themselves much more frequently in a random manner (Figure 3). The following ballistic effects have to be considered in turbulence climatology (Table VI):

a. Scale of turbulence, which indicates the size of the eddies of the air flow, representing turbulence.

b. Both absolute and relative frequency of occurrence of the significant eddy sizes.

c. Frequency spectrum of both eddy sizes and eddy intensities with regard to potential resonance effects in the control and guidance system of the rocket and the aeroelastic properties of the rocket-shell structure.

d. Angle-of-attack increment, which is also of much shorter duration than in the case of wind shear.

e. Disturbing angular accelerations of the rocket axes, causing non-stationary aerodynamic moments of short duration but with high frequency of occurrence.

A turbulence climatology in the true sense, either on local or global scale, is non-existent. For the analysis of aircraft performance, so-called "gust-speeds" have been statistically evaluated (Press, Reference 13). In Figure 12, these "gust-speeds", as measured during aircraft flights, are compared with statistical evaluations of short period wind-speed fluctuations measured on rocket flights (Vaughan, Reference 11). In this graph, both the median (50 percent) and the 99.9 percent frequencies of occurrence of gusts for both aircraft (dashed line) and rocket measurements (solid line) are plotted versus altitude. It is quite obvious that significant peaks of the gust speeds are missing in the aircraft-measured data. Also, the aircraft measurements indicate a bulge of gust speeds around two kilometer altitude. This fact might be explained by the larger population of aircraft data broadly covering all turbulence conditions in the western half of the northern hemisphere. The rocket-measured turbulence data originated uniquely in the Cape Canaveral firing range. The described discrepancies of the two sets of gust data illustrate the urgent necessity of much more extensive measurements of atmospheric turbulence, utilizing refined methods of high resolution as applied with the presented rocket measurements (Reisig, Reference 14). Only with such measurements of sufficient detail, the urgently-needed global turbulence climatology could be established.

4. Specific Ballistic Aspects of Wind Influence on Rockets. The significance of wind parameters for rocket ballistics may be illustrated by a few more dynamic implications.

First, in Figure 13, the contribution of the windspeed to the airflow velocity is presented for two different trajectories of a two-stage, tactical ballistic rocket with 750 kilometer ballistic range. These two types of trajectory are distinguished by the different duration of the coasting periods between the two propelled phases of the ascenting flight path of this rocket configuration.

The two trajectories are affected by either the median (50 percent) or the 99.9 percent frequency of occurrence of the global windspeeds. In the median case of windspeed occurrence, the influence on the airflow velocity is in the order of 1 percent. For the 99.9 percent frequency, however, the influence of the wind may increase up to 20 percent of the airflow velocity. Such magnitudes of wind component would produce angle-of-attack values of over ten degree, which creates a severe condition for the structural integrity of the rocket shell. For illustrating this statement, Figure 14 explains the relations between rocket velocity, windspeed, and angle-of-attack in the "Velocity Triangle". It is seen that the angle-of-attack is included between the rocket velocity vector ($v_{gr}$) and the vector of the airflow velocity against the rocket shell ($v_a$). The wind velocity (w) represents the closing vector in this velocity triangle. It is evident from the graph that, for a given rocket velocity, the angle-of-attack is determined by the instantaneous magnitude of the wind vector. For simplicity, it is assumed in Figure 14 that the wind blows parallel to the surface of the earth, and that the attitude of the rocket axis is identical with the direction of the tangent to the trajectory (direction of $v_{gr}$).

The significance of windspeeds influencing the aerodynamic loads on a rocket shell may be seen from Figure 15. This graph shows the dynamic pressure versus flight altitude of a ballistic rocket with 325 kilometer ballistic range, together with the allowable angle-of-attack for this rocket configuration. The indicated angle-of-attack values are determined by the aerodynamic load which the structure of the rocket shell can marginally stand under the prevailing dynamic pressure. It is seen from the graph (Figure 15) that the allowable angle-of-attack is a minimum at the altitude range of the highest wind speeds in the troposphere, as indicated by the jet stream altitudes. This controversial ballistic condition might prohibit a rocket firing in case of a very strong jet stream being present above the launching area. This sample illustrates quite well the importance of knowing the intricate atmospheric conditions for firing a rocket successfully.

Another sample of wind effects on rocket performance is concerned with attitude stability. As a matter of experience, an angle-of-attack of one-half degree is considered the threshold value for attitude stability investigations of the control system. It is now interesting to know which windspeeds produce this marginal angle-of-attack value along the rocket trajectory (Figure 16). By comparing several rocket types, it turns out that the selected type of a two-stage ballistic rocket is, in general, somewhat less sensitive to wind influences than the two other ballistic rocket configurations of 325 and 2800 kilometer ballistic range. This means the referenced two-stage ballistic rocket can stand somewhat higher windspeeds than the other two rocket types before an angle-of-attack of half a degree develops. Above 40 kilometer altitude, the rocket with 325 kilometer ballistic range is the most sensitive configuration, with about 20 meter per second windspeed for half a degree of angle-of-attack.

This windspeed value remains valid up to about 60 kilometer altitude. Since windspeeds between 10 and 20 meters per second begin to affect the rocket attitude from 20 kilometers altitude upward, it appears necessary to know the individual wind conditions throughout the stratosphere, as a routine measure for rocket flights.

A last sample may illustrate the bearing of fast changes of wind velocity, or gusts, on the structural strength of a rocket shell, in terms of bending moments. Figure 17 represents the bending moments of the shell of the SCOUT rocket indicating the suppression of peak loads because of the application of the smoothing rawinsonde measuring technique for wind data (dashed line), in comparison to the detailed, "true" wind data from the smoke trail wind measurement (solid line) (Rhode, Reference 15). The rawinsonde wind data, representing essentially the mean windspeed profile (Section II. A. 1), falsify the true peak bending loads by a factor larger than four. Neglecting the instantaneous detail features of the vertical windspeed profile may very well result in structural failure of a rocket shell. The necessity of quick-response and true-amplitude wind-measuring systems is most obvious from the given samples.

5. Density Climatology. As mentioned before, density is one of the two predominant atmospheric parameters in ballistics (Table VII). Its importance derives from the fact that density is one of the constituents of dynamic

pressure. Dynamic pressure enters practically into every aerodynamic quantity of any bearing, such as drag, lift, aerodynamic force, etc. No trajectory calculation could be made without dynamic pressure information, and, hence, without density information.

Other aerodynamic parameters depending on density are Reynolds number and Prandtl number which enter , to a large degree , into boundary layer and heat transfer problems, as mentioned before.

Global density climatology is still in a relatively unsatisfactory condition. Figure 18 shows the consolidation of the average density deviation from the reference standard derived from five stations (Reisig and Alfuth, Reference 16). Of course, these few stations cannot be considered representative for the whole globe. For practical purposes of numerical treatment, density values are given as RMS deviations from a reference standard density profile. The ARDC Standard Atmosphere has been chosen as the reference density standard. This improvised global density profile, nevertheless, clearly indicates the layer of almost constant density at about eight kilometer altitude. This layer of minimum density deviation was discovered by Linke (Reference 17), some forty years ago. Another layer of minimum density deviation can be recognized between 20 and 25 kilometer height. The recent investigations of Faust and his associates (Reference 18) characterized this altitude band of minimum density deviations as a second Linke layer.

Another approach to quantitative presentation of density criteria for rocket design has been followed by Alfuth and collaborators (References 19 and 20). In their analysis, the statistical density fluctuations are presented in terms of polynomials as functions of large geographic areas and of the seasons of the year. The coefficients of the two-dimensional polynomials of up to the fifth degree were determined by means of the method of least squares. The twelve monthly mean values of air density for each of fifteen stations served as input for the computation of the polynomials at 25 altitude levels, with altitude increments of one kilometer. Figures 19 through 22 show samples of the obtained density polynomials. Figures 19 and 20 were selected from the altitude region of maximum density deviation from the ARDC standard density (Figure 18) around 12 kilometer altitude. Figure 19 presents the absolute density values as a function of the month during the year for three different latitudes. As can be seen, the density variations at a subtropical latitude are very slight over the year. The amplitude of the density variation increases with higher geographical latitudes, and is always positive. The maximum density value at this altitude level occurs between July and August, and amounts to a maximum of 10 percent at 45 degree latitude. Figure 20 shows the density values versus geographic latitude for the four seasons of the year at 12 kilometer altitude. At this height in the atmosphere, the density data uniquely decrease from lower to higher geographical latitudes. Also, the density is highest in summer (July) and lowest in winter (January) at any latitude.

In comparison and in contrast to the density variations at 12 kilometer altitude, or above the first Linke layer, Figures 21 and 22 show the corresponding density variations at 4 kilometer altitude, or below the Linke layer. Comparison between Figures 19 and 22, and Figures 20 and 22, indicates that the respective density profiles at 4 kilometer altitude appear mirrored about a horizontal axis from the profiles at 12 kilometer altitude. That means, the density values, at least at both 45 degree and 10 degree latitude, reach a minimum during summer (Figure 21), and they increase from lower to higher latitudes during all four seasons of the year (Figure 22).

The presented graphs may demonstrate the climatological potentialities of the polynomial method. The analytical approach still has to be refined to include the third dimension, which is geographic longitude. At least, the available polynomials of atmospheric density permit approximate mean density profiles to be established in geographical areas which are not covered by meteorological stations.

Rocket design experience shows that cumulative frequency density profiles, as indicated for 50 percent probability in Figures 18 through 22, do not suffice as input into problems of ballistic analysis. As in the case of wind climatology, the "historical" shape of the individual density profile has to be preserved in contrast to the envelope features of the cumulative frequency profiles. Again, this requirement calls for the derivation of populations of typical density profiles, representing the density properties of significant weather situations.

A first investigation on the topic of typical mean density profiles has been performed by Essenwanger (Reference 21). The few test cases proved that for extratropical stations the fit of a density profile by means of a three-term polynomial was already representative by more than 85 percent of the original profile. Hence, it appears justified to develop a density climatology based on classes of polynomial coefficients, representing typical density profiles associated with typical weather situations.

In Table IV A and B, the individual stations are listed for which the conventional aerological climatology of atmospheric density is available at this date.

6. Pressure Climatology. The atmospheric pressure also is one of the basic parameters in the aerodynamic aspects of ballistics. Pressure distributions around ballistic shells are the key to their aerodynamic behavior. The following ballistic effects are listed for illustration ( Table VIII):

a. Pressure Coefficient. The pressure distribution around any flying body is characterized by the pressure coefficient, $C_p$. As indicated in Table VIII, $C_p$ is proportional to the difference between the static pressure on the surface of the body and the pressure in the undisturbed air flow, which is the ambient atmospheric pressure ($p_a$) in case of a rocket flight. The pressure coefficient essentially determines the drag of a body, and also enters into the lift determination. Hence, deviations of the actual atmospheric pressure from a standard atmosphere should be known in aeroclimatological terms.

b. Base Drag. This type of drag results from the difference of the pressure at the rear of a rocket shell and the ambient atmospheric pressure. In certain Mach number ranges and for certain rocket configurations, this base drag may be as high as 60 percent of the total rocket drag. For optimizing the base drag behavior of a certain rocket configuration, the global atmospheric pressure climatology has to be known.

c. Thrust Gain. This phenomenon is due to atmospheric pressure acting as a counter pressure against the nozzle-exit pressure of the rocket engine. Decreasing external pressure raises the effective thrust of the engine. In the case of an engine with 60,000 kp thrust in a rocket of 2800 kilometer ballistic range, this thrust gain is a maximum of 18 percent. The pressure climatology is needed to optimize this pressure gain over the entire propelled flight period of the rocket.

d. Density Determination. The density so far is not a primary quantity of meteorological routine measurements. In terms of the state of gas equation, the atmospheric pressure determines the atmospheric density in conjunction with the atmospheric temperature.

Up to now, a global pressure climatology as a function of altitude does not exist. Table IV A and B contains a listing of the stations for which conventional aerological climatologies of atmospheric pressure are available at this date.

7. Temperature Climatology. The gas temperature enters into any intricate analysis of the air flow around ballistic shells. The following ballistic parameters may be quoted for illustration (Table IX):

a. Density Determination. Besides atmospheric pressure, the atmospheric temperature is the decisive factor in determining the atmospheric density in terms of the state of gas equation.

b. The Mach number is dependent on the atmospheric temperature in terms of the velocity of sound.

c. The Reynolds number depends in two ways on temperature, the latter determining both viscosity and density.

d. The Prandtl number also depends two-fold on temperature, the latter incurring into both viscosity and density.

e. Drag Coefficient. The ballistic significance of atmospheric temperature becomes duly evident from the trend of the drag coefficient which depends on both Mach number and Reynolds number, as well as on Prandtl number in the case of hypersonic flight. Variations of atmospheric temperature thus influence the range of rockets by means of corresponding drag variations, which include the temperature effects on both atmospheric density and coefficient of drag (Roth and Saenger, Reference 22).

f. Aerodynamic Heating. Atmospheric temperature enters as a basic factor into the stagnation temperature, which controls the very important heating problems of rocket shells traveling at supersonic speeds. The efficiency of heat stagnation is controlled by both the Reynolds and Prandtl number, which introduces a more complex dependence on temperature.

The situation with the climatology of atmospheric temperature is just as unsatisfactory as with pressure climatology. A global temperature climatology does not exist at all. The stations for which local aerological temperature climatologies are available at this time are listed in Table IV A and B.

8. Hydrometeor Climatology. From flight experience with high-speed aircraft, and from a few wind tunnel tests, the destructive effects of hydrometeor impacts on flying bodies have become known. Rocket shells traveling at speeds of Mach numbers three to five times greater than those of the fastest type airplanes might experience near-fatal damage when impacted by hailstones or even large rain drops. Other types of hydrometeors to be considered for the potential damage to rocket shells, or functional failure of outside instrumentation, include graupel, ice crystals, ice pellets (sleet), snow flakes, or even cloud droplets, if aerodynamic condensation effects should be involved (Table X).

The hydrometeor interference with rocket shells is a severe aerodynamic problem as well as a problem of atmospheric physics and aerological climatology. The aerodynamic aspects of the hydrometeor problem will be discussed in more detail in Section II. B. 2. A typical example of adverse aerodynamic effects of hydrometeors on vital rocket components is the potential clogging of angle-of-attack meters in supercooled rain clouds. Also, the modification of aerodynamic profiles by adhering hydrometeors usually has adverse effects on the flight performance of bodies, as is well known from airplane operation. As far as the atmospheric properties of the hydrometeoric phenomena are concerned, the following climatological parameters have to be analyzed:

a. The frequencies of occurrence of the types of hydrometeors, as quoted above, particularly in relation to specific weather situations. These synoptic conditions should preferably be expressed in terms of characteristic profiles of temperature, humidity, and any other pertinent atmospheric parameter, as, possibly, vertical wind shear.

b. The frequency distributions of momentum (i.e., mass times flow velocity) of discrete hydrometeor individuals in the free atmosphere.

c. The frequency distributions of the geometric size of the hydrometeoric individuals, or their configurations in general.

Proper investigations on hydrometeor climatology are still in the preliminary stage (Vaughan, Reference 23). Conventional meteorology is primarily concerned with studying the precipitation falling on the ground, but is concerned to a much lesser degree with the history of the hydrometeors in the higher atmosphere supplying the precipitation. Much effort is still necessary before adequate statistical data could be processed into a hydrometeor climatology. A promising experimental project on free-atmosphere measurements of hydrometeors is underway at the Institute of Technology at Karlsruhe (Germany), being sponsored by the U.S. Army Signal Corps.

9. <u>Radiation Climatology.</u> In various altitude regions of the atmosphere, particularly above the troposphere, many different types of energy radiation may be encountered. Typical radiation species include (Table XI) infrared, visible, ultraviolet, cosmic ray, gamma, and nuclear radiation. Possible ballistic effects of these radiation types could consist of:

a. Defects to the structural strength of rocket shells.

b. "Clogging" of flight instrumentation.

There are, by far, not enough physical facts known about the eventual interference of such type radiation with structural material. Detrimental effects of radiation on flight instrumentation might be more easily accessible. A radiation climatology could not be expected for some time. First, upper air radiation measurements would have to be established as a routine operation.

10. Status of Aerological Climatology. At the conclusion of the survey on Rocket Design Climatology, a brief review shall be given on the present status of aerological station climatology as far as being compiled in the Climatological Ringbook of the Army Missile Command.

In 1957, Army Missile Command[1] initiated the establishment of the "Climatological Ringbook" for tabulations of aerological climatologies. Systematic and consistent work on this project resulted in the edition of 22 volumes of this ringbook until September 1, 1962, covering 15 worldwide stations. The data of 32 more stations have been prepared for computing the frequency distributions, or are in the process of preparation (Table IV A and B; Figures 23 and 24). Much effort is being spent to optimize the numerical quality of the raw data. The wind data of the American and Asian stations were scrutinized at the U.S. National Weather Record Center (Essenwanger, Reference 24). For the European stations, a comprehensive scientific program is being performed by Professor Scherhag's Institute [2] for the homogenizing and supplementing of the raw data, with application of synoptic analysis of individual weather situations.

Electronic computer programs have been established for the derivation of frequency distributions of the aerological parameters (Alfuth, References 2 and 25). All tabulated aerological data are given as a function of altitude in intervals of 1000 meters up to the radiosonde ceiling. One computer program for winds and one for the "thermodynamic" parameters of the atmosphere has been established respectively. The latter includes pressure, temperature, humidity, and density. The tabulations of the thermodynamic volumes of the ringbook give cumulative frequencies of pressure, temperature, and density as deviations from the ARDC Model Atmosphere, 1959, for 12 months and the total year. The cumulative frequencies are given at eight frequency levels[3] and, additionally, the minimum and maximum values at each altitude level.

---

[1] At that time: Army Ballistic Missile Agency (ABMA).

[2] Institut fuer Meteorologie und Geophysik der Freien Universitaet Berlin.

[3] Cumulative frequency levels: 0.135; 2.28; 15.9; 50.0; 68.0; 84.1; 97.72; 99.86 percent.

The wind data are given at the same frequency levels, with the same altitude intervals, and for the same time periods as the "thermodynamic" quantities. The wind parameters included in the tabulations are scalar wind speeds, and zonal, meridional, easterly, westerly, northerly, and southerly wind components. A unique feature of the aerological wind climatologies are the frequency distributions of vector wind shear, applying scales of distance of 500 meters up to 3 kilometers altitude, and of 1000 meters at heights beyond 3 kilometers.

It is definitely anticipated that the ringbook parts of both the wind and thermodynamic series, of at least 30 more stations, will be published by the middle of 1963.

## B. TOPICS IN ATMOSPHERIC ROCKET PHYSICS

Even a high-quality climatology is rather useless if the physical laws are not known which control the ballistic effects of the climatological parameters. Hence, physical and mathematical methods have to be developed which yield a quantitative treatment of the specific reactions of the rocket shell and its components to particular atmospheric effects. The intricacies of these interactions between rockets and the immediate surrounding atmosphere are the topics of atmospheric rocket physics.

From the wide scope of problems in atmospheric rocket physics, some of immediate interest to advanced rocket development may be selected, namely (Table XII):

a. Atmospheric turbulence (gust) dynamics.

b. Hydrometeor impact dynamics.

c. Atmospheric rarefied gas physics.

d. Exploration of the ignosphere.

A brief outline will explain the particular physical features of the quoted topics in atmospheric rocket physics.

1. <u>Atmospheric Turbulence (Gust) Dynamics</u>. The mechanics of turbulence or gustiness are by far not adequately understood. This is a severe handicap to the analytical treatment of rocket stability and the impact of nonstationary aerodynamic forces which is an urgent problem of rocket ballistics.

The objectives of investigations in turbulence dynamics are as follows (Table XIII):

a. Criteria for the recognition of turbulence from empirical data of the free atmospheric air flow. The characteristics of turbulence should be expressed in terms of the physical features of the wind field. The final goal of this concept is the derivation, or even the forecasting, of turbulence parameters from characteristic wind and wind-shear profiles.

b. Analysis of the spectra of both turbulence intensities and frequencies which are connected with the eddy sizes of the turbulent air flow. The goal of these investigations is the establishment of a mathematical model of the physical properties of atmospheric turbulence, particularly in terms of eddy intensities and frequencies, or wave lengths, including also statistical features, like the probability of occurrence of discrete ranges of the turbulence spectrum.

c. An intrinsic topic of the mathematical turbulence model is concerned with the eddy formation in free-boundary shear flow, since this condition of atmospheric flow appears to be responsible for the major part of occurrence of atmospheric turbulence. The intricate problem of generation and dissipation of atmospheric turbulence cannot be solved reasonably without a large amount of specific observational data. Rocket flight measurements, on board of both sounding rockets and booster-type vehicles, are the most proper tools for this purpose. A first result of determination of the scale of turbulence is shown in Figure 25. For this statistical presentation, the raw data have been taken from the fast wind-speed fluctuations of rocket-measured wind profiles above Cape Canaveral, Florida. The eddy size or scale of turbulence has been derived in terms of Prandtl's "Mixing Length". Under this concept, Prandtl assumes that the turbulent flow components consist of batches of the flowing medium. These batches have a relative motion perpendicular to the main flow direction, exchanging momentum between flow "layers" of different main flow velocities. The "Mixing Length" is now the distance, perpendicular to the mean flow direction, at which a moving batch of flowing medium loses its individual existence by mixing with the surrounding fluid. It turns out that the mixing length is also a measure for the dimension of the involved batch, or eddy, of the fluid. Thus, the mixing length is an appropriate measure of both the eddy sizes of the turbulent flow and the relation between the mean flow velocity and its turbulent fluctuations.

Three prominent features may be derived from Figure 25, namely:

a. There seems to exist a turbulent "basic noise" in the atmosphere which could be represented by the 50 percent frequency of occurrence (median), which is close to the "average" turbulence condition. The eddy sizes of this "basic noise" increase slowly, in an almost parabolic fashion, with altitude. It starts with a mixing length of about one meter near the surface, and nearly stabilizes above 20 kilometers altitude with a mixing length of approximately four meters.

b. With the higher levels of frequency of occurrence (98 percent and above), several prominent layers of increased eddy sizes are evident. The altitude levels of these layers of obviously more intense turbulent flow may be typical. The layer at five kilometers altitude appears remarkable, but the layer between 15 and 20 kilometers altitude may be expected, as being on top of the jet stream, in the region of receding wind speeds. A third layer of more heavily turbulent flow is found between 27 and 35 kilometers altitude. This turbulence region is situated below the third wind speed maximum, which has been found statistically at about 40 kilometers altitude in the Cape Canaveral, Florida, windfield (Reisig, Reference 26).

c. The envelope of the peak magnitudes of the scale of turbulence as a function of altitude appears approximately as a straight line with a positive slope. This increase of turbulence intensity with height certainly is opposite to the common opinion of decrease of turbulence intensity with height in the surface layer.

For intricate measurements at lower flight speeds, a wind shear and turbulence dropsonde has been developed in conjunction with the Army Signal Corps (Figure 26). The wind-speed fluctuations are determined from the ratio of measured lateral accelerations and forward airflow speed against the falling body. In Figure 26, the two lateral accelerometers are seen just beneath the lower edge of the central ring wing, with their sensitivity axes perpendicular to each other. The airflow speed in the direction of the longitudinal axis of the dropsonde is measured with an air log. The horizontal orientation of the sensitivity axes of the accelerometers is determined by an azimuth meter of the magnetic type. The perpendicular orientation of the dropsonde is to be secured by the double-ring wing configuration. With these physical premises, the vertical wind shear can be determined in each of the two vertical planes according to:

$$WS_h = \frac{a_L}{V_h} = \frac{\Delta V_L}{\Delta t} \cdot \frac{\Delta t}{\Delta h} = \frac{\Delta V_L}{\Delta h} \equiv \frac{\Delta W}{\Delta h}$$

$WS_h \triangleq$ vertical wind shear

$a_L \triangleq$ lateral acceleration

$\Delta h \triangleq$ height interval

$\Delta t \triangleq$ time interval

$\Delta V_L \triangleq$ horizontal flow velocity change

$\Delta W \triangleq$ horizontal wind change

The four measured quantities, that is, two lateral accelerations, the vertical flow velocity, and the azimuth are to be telemetered to the ground. The flight path of the dropsonde is to be tracked from the ground by cinetheodolites or precision radar. In the operational version, the dropsonde is to be carried aloft by a high altitude balloon with automatic release. The first instrumented drops of these wind-shear sondes are scheduled by the U. S. Army Signal Corps for the immediate future.

2. Hydrometeor Impact Dynamics. The specific mechanics of hydrometeor impacts on fast-flying bodies are only slightly known (Goetz, Reference 27). The aerodynamic aspects of hydrometeor interference are primarily the following three: (Table XIV)

a. The interaction of the hydrometeoric elements with the shock wave in front of the nose of rocket shells at supersonic speeds.

b. The trajectories of the hydrometeoric elements around the rocket shell.

c. The change of shape of the rocket shell due to mass interchange between hydrometeors and rocket.

As far as the shock wave interference of the hydrometeors is concerned, it has been found from laboratory experiments that even water drops do not break up inside the shock (Engel, Reference 28). The break is deferred to the space between shock wave and body. It only takes place, however, if sufficient time is available before the integer hydrometeoric element might hit the surface of the rocket. Sufficient travel time of the hydrometeor can be expected at low supersonic Mach numbers at blunt rocket noses. With higher Mach numbers, the distance between bowed shock wave and body becomes increasingly shorter, and a higher Mach number could be anticipated at which the hydrometeoric element would hit the body as an integer with full impact.

Ice particles could coagulate at the front of the nose cone if the stagnation heat could only melt the ice particles to a certain degree but not liquify them. Changes of the body shape, caused by collected hydrometeors, could endanger the stability of the rocket shell.

The icing of angle-of-attack meters from supercooled rain, for instance, would be a corresponding sample of the potential clogging of vital rocket flight instruments.

The analysis and physical explanation of the quoted phenomena needs an extensive amount of empirical data. These are to be obtained from wind tunnel and ballistic range experiments, as well as from frequent flight measurements in the free atmosphere. For the latter part of the hydrometeor program, the proper instrumentation still has to be developed, which should be carried aloft either by meteorological and ballistic rockets, by balloon sondes, and airplanes. These hydrometeor probes impose a substantial number of difficult and unusual problems on the art of measuring. Some experience has been gained from meteorite impact measurements on satellite vehicles. A common impact gauge is of the microphone type with a suspended diaphragm. It has been found, however, that the response of a diaphragm depends on the impact location on the diaphragm. Japanese atmospheric physicists designed a shrewd remedy to this measuring deficiency of the microphone. They mounted a cone-shaped cap on top and in the center of the diaphragm, so that the whole configuration resembles somewhat the shape of a mushroom. Any particle impact at any location on the cone is thus referred to the same elastic conditions in the center of the diaphragm.

The significance of hydrometeoric impacts on rocket shells probably is more realistic than commonly anticipated. It is believed that at least one ballistic rocket was lost on a test flight between Cape Canaveral, Florida, and the impact area in the waters between the West Indian Islands because of potential interference with hydrometeors suspended in the atmosphere. An almost perfect test flight of a rocket was abolished a few seconds before successful completion, due to the presence of a very natural and common feature of the atmosphere like a heavy rain cloud in the tropics. Such events, by themselves, emphasize the necessity of thoroughly investigating the hydrometeoric impact problem with regard to successful rocket flights.

3. Atmospheric Rarefied Gas Physics. The continuous refinement of advanced rocket systems no longer allows the ballistic phenomena at low air densities in the higher atmosphere to be neglected. The re-entry problems of ballistic bodies are to a large part tied to the conditions at low densities in the high atmosphere. The regime of low gas densities pertains to the field of rarefied gas physics which no longer deals with a gas continuum, but with the basic molecular structure of the gas. As a matter of fact, three regimes of rarefied gas flow are distinguished (Table XV):

a. Slip-flow regime, which is characterized by large viscosity effects or large compressibility effects or both.

b. Transition flow regime.

c. Free-molecule flow, characterized by mean free path lengths larger than the body dimensions.

The degree of rarefaction of the mass of gas flow increases from slip flow through transition flow to free molecule flow with the lowest gas density being encountered.

Analytically, the regimes of rarefied gas flow are characterized by the Knudsen number, Kn. It is defined as the ratio of the mean free path of a molecule ( $\lambda$ ) to a reference length (L), for instance, the longitudinal dimension of a rocket shell:

$$Kn = \lambda/L.$$

Also, from a physical aspect, the Knudsen number can be expressed by other non-dimensional parameters. Thus, the Knudsen number is proportional to the ratio of Mach number to Reynolds number;

$$Kn \approx Ma/Re$$

The rarefied gas phenomena have a substantial impact on aerodynamic properties of a high-speed airflow past a body. Particularly in free molecule flow, the incident airflow is not disturbed by the presence of the flying body (Schaaf, Reference 29). The aerodynamic forces on the rocket shell depend on its temperature. Under slip flow boundary conditions, both skin friction and heat transfer are reduced (Schaaf, l. c.).

For analyzing the complex physical conditions during a rocket flight in the rarefied gas regime, a considerable amount of atmospheric measurements has to be taken. These measurements are of general ballistic significance since really low densities are much easier to obtain in the high atmosphere than in intricate laboratory "test tubes" (e.g., evacuated ballistic range). Ballistic and sounding rockets provide highly useful empirical information when carrying specialized measuring equipment aloft. However, the measuring methods themselves are subject to the rarefied gas phenomena. This is particularly true for such basic atmospheric parameters as density and temperature. Especially, ambient temperature becomes a dubious physical quantity in a highly diluted gas. For instance, it has been suggested to characterize the temperature condition of a rarefied gas flow by its enthalpy value, rather than by the amount of the mean kinetic energy of the gas molecules which are supposed to be in the state of instantaneous thermal equilibrium. The latter is a controversial physical condition in the rarefied gas regime.

One interesting, and possibly significant, result has already been obtained with a set of measurements of the stagnation temperature with ballistic rocket test flights. Figure 27 shows a comparison between the measured total temperature and the values to be expected, as calculated from the tracked rocket velocity and the measured atmospheric temperature, applying the enthalpy method. It is evident that above Mach number 4.5, which occurs between 40 and 45 kilometers altitude, a severe deviation between the measured and the expected temperatures occurs. Here the rocket definitely flew through the rarefied gas regime. After correcting the measured data for radiation losses and the particular Mach number effects on the temperature gauge in this regime, the stagnation temperature ($T_t - T_a$) at the gauge is higher than expected from the translational energy of the impacting gas flow. This means a recovery factor larger than one in the relation:

$$T_t = T_a \left(1 + r \cdot ((\gamma - 1)/2) \cdot Ma^2\right)$$

$T_t \mathrel{\hat{=}}$ total temperature

$T_a \mathrel{\hat{=}}$ ambient temperature

$r \mathrel{\hat{=}}$ recovery factor

$\gamma \mathrel{\hat{=}}$ ratio of specific heats

$Ma \mathrel{\hat{=}}$ Mach number

In other words, the stagnated heat amount (proportional to $(\gamma - 1) \cdot Ma^2/2)$ is larger than the converted amount of kinetic energy of the airflow against the rocket shell. This phenomenon is being explained by the theory of free molecule flow (Schaaf, l.c.), and has also been experienced with some wind tunnel tests (Stalder, Reference 30).

For more intricate investigations of these unconventional rarefied gas effects, the measurement of the atmospheric temperature has to be improved substantially, as mentioned before. As can be seen in Figure 27, the radiosonde delivers the atmospheric temperature only up to Mach Number 4, just below the most interesting region. The missing temperature data have to be supplied from sounding rocket measurements.

Figure 28 shows a conventional measurement of ambient temperature obtained from a sounding rocket firing at Cape Canaveral, Florida. The ARDC Standard Temperature is included for comparison, as it has been used for temperature extrapolation above the radiosonde ceilings. Such measurement proves that there really exists a need for sounding rocket firings simultaneously with ballistic rocket firings for purposes of analysis of rocket flight performance.

4. Exploration of the "Ignosphere". During the discussion of the foregoing topics of atmospheric rocket physics, the necessity for extensive measurements of atmospheric parameters at high altitudes has been stressed numerous times. It is a surprising fact that the altitude region between the radiosonde ceilings (about 30 km) and the lowest satellite orbits (about 100 km) suffers from the greatest lack of atmospheric information in comparison to the altitude regions covered either by radiosondes or satellites. Because of the ignorance on intricate atmospheric conditions between approximately 30 and 100 km altitude, famed Professor Spilhaus of the University of Minnesota baptised this distinguished altitude region the "Ignosphere" (Table XVI). Extensive increase of atmospheric data collection pertaining to the ignosphere would not only benefit the area of atmospheric physics, but the area of rocket design climatology as well, having the extended operational altitudes of future rocket models in mind.

After all, for the sake of atmospheric rocket ballistics, the dynamic behavior of the atmosphere has to be understood as a whole, and should not be restricted to a random altitude level just by the fact that a convenient measuring system, like radiosondes, fails above this altitude level. The first significant achievement toward routine measurements beyond the radiosonde ceiling and into the higher stratosphere, is the establishment of the Meteorological Rocket Network in North America. Figure 29 shows the location of the eight stations now participating in the synoptic upper atmosphere measuring program (Aufm Kampe, Reference 31). Daily ascents of ARCAS and LOKI meteorological rockets are performed, except on weekends, during the midmonth of each season, providing both wind and temperature data up to 75 kilometer altitude.

It is also believed that wind measurements on board ballistic rockets made a significant contribution towards the recognition of the actual structure of both the low and high regions of the atmosphere. Figure 30 shows a detailed windspeed profile measured with a rocket flight over Cape Canaveral, Florida. The windspeed profile indicates three layers of wind maxima on top of each other, and not just one, as commonly assumed until a few years ago. The maximum windspeeds occur at 11, 29, and 46 kilometer altitude. It is significant that the highest wind maximum also is the strongest and has a speed of 100 meter per second. Such strong air currents at these high altitudes have been confirmed in the meantime by numerous rocket measurements, particularly over Cape Canaveral, Florida, and Fort Churchill, Canada. But if these strong currents exist, also strong temperature differences and, thus, density differences must exist between different areas in the atmosphere. It is felt that investigations in atmospheric rocket physics should include the mechanics and dynamics of such substantial density gradients in the high atmosphere with regard to their ballistic significance.

The Ignosphere typically is the realm of the atmosphere for rocket soundings. Hence, it is strongly expected that a European Meteorological Rocket Network very soon shall join the stratospheric measuring program in North America (Faust, Reference 32). The mere existence of the "Ignosphere", after four years of extensive satellite measuring activities, greatly justifies the firing of meteorological rockets on a regular, dense schedule over a widespread geographical area. In addition, special sounding rockets with "sophisticated" instrumentation should be fired in a program for investigating the basic physical aspects of the Ignosphere. The goal of the regular Ignosphere soundings is the tie-in of atmospheric data between the radiosonde regime and the satellite regime. Finally, an "Ignosphere Climatology" is to be established compatible with, and equivalent to the growing rocket climatology, which is now bound by the radiosonde ceiling.

## C. ATMOSPHERIC ENVIRONMENTS FOR ROCKET FIRINGS

In the foregoing sections, it was outlined in detail how many ways atmospheric parameters could affect the rocket flight performance. Hence, if it comes to an actual rocket firing, the following three groups of atmospheric aspects have to be incorporated into the firing preparations, and into flight performance appraisal and evaluation (Table I):

a. The programming and scheduling of a rocket firing, and the prediction of the rocket flight performance have to be analyzed in terms of the expected atmospheric conditions at the time of the firing.

b. The safety of the firing range and the rocket itself has to be checked at firing time as to eventual adverse atmospheric conditions.

c. The actual atmospheric parameter values have to be known which were prevailing during the rocket flight. These atmospheric "in-flight data" are needed for the post-flight analysis of the rocket behavior along its trajectory.

1. Atmospheric Aspects of Rocket Flight Programming. The atmospheric aspects of rocket flight programming are based essentially on the aerological climatology of the firing range. The following atmospheric implications shall be quoted with respect to a successful and efficient rocket performance (Table XVII):

a. The first group of atmospheric effects on proper rocket flight performance is concerned with rocket stability. Stability appraisals have to consider climatological records of wind, wind shear, and gusts, and the probability of hydrometeoric effects on rocket stability has to be analyzed as well.

Marginal stability situations might occur during the flight phase of maximum dynamic pressure (Figure 15), and in the transonic range ( around Mach number one), or during flight periods of negative aerodynamic stability parameters of the body in the higher Mach number ranges. These stability studies are usually performed on an analog computer, using climatological windspeed-, windshear-turbulence-, and density profiles as perturbation functions.

For securing proper rocket stability, the gain factors of the control and guidance loops have to be adjusted according to expected atmospheric conditions. If the available control-range adjustments cannot match the expected atmospheric conditions, the particular rocket flight might have to be either advanced or postponed in order to benefit from more favorable climatic probabilities for a stable rocket flight. This situation actually happened with one rocket firing of the JUNO II -series, for which the control and guidance system had to satisfy a particularly rigorous stability condition. For the scheduled firing date, however, the climatological probability of the wind situation at Cape Canaveral, Florida, did not guarantee stable flight conditions of the rocket. Thus, the firing date had to be advanced to the climatologically more favorable, warmer season in order to avoid very costly and time-consuming modifications of the control and guidance system.

b. Second, for each rocket firing, the most likely flight trajectory has to be determined in advance. Again, climatological data valid at the scheduled firing date have to be utilized for the trajectory integration. In the ascending, powered part of the rocket flight path (Figure 31), the atmospheric conditions have to be compatible primarily with the performance characteristics of the control and guidance system of the rocket. However, on the ascending and descending parts of the ballistic (i. e., unpowered) flight path, usually control or guidance functions are no longer executed. The flying body is then fully exposed to atmospheric influences of various kinds, primarily wind and density variations.

The theoretical trajectory of the ballistic body is usually being calculated under the assumptions of zero windspeed and both standard density and temperature profiles as taken from the ARDC model atmosphere. However, the actual trajectory is flown by the rocket under the influence of a definite wind profile, and very likely with a density profile which deviates from the standard conditions of the model atmosphere. Both actual profiles have to be valid specifically for the geographic location of the ballistic trajectory, and the time of the rocket firing.

The ballistic body has different sensitivities to wind influences and density changes at different altitude levels on its trajectory. These sensitivities depend mainly on the weight-to-drag ratio of the body. Accordingly, variations of the impact point of the re-entry body ($\Delta R_W$; $\Delta R\rho$) may be expressed in terms of these sensitivity factors for both wind ($\partial R/\partial w$), and density deviations ($\partial R/\partial(\delta\rho)$):

$$\Delta R_W = [\partial R/\partial w] \cdot W,$$

$$\Delta R\rho = [\partial R/\partial(\delta\rho)] \cdot \delta\rho \text{.}$$

In Figure 31, the trajectory has been split into altitude layers, each of which is characterized by a set of sensitivity factors $(\partial R/\partial w)_i$; $(\partial R/\partial(\delta\rho))_i$

For each such altitude layer, the values of wind and density deviation are taken from a local and timely wind profile and a density-deviation profile. Then, the individual range deviations of each altitude layer are summed up to the total range displacement of the re-entry-body impact:

$$\Sigma\Delta R = \sum_i (\partial R/\partial w)_i \cdot W_{Ri} + \Sigma (\partial R/\partial(\delta\rho))_i \cdot \delta\rho_i .$$

The same procedure is valid for the crossrange displacement:

$$\Sigma\Delta C = \sum_i (\partial C/\partial w)_i \cdot W_{Ci} + \Sigma (\partial C/\partial(\delta\rho))_i \cdot \delta\rho_i .$$

The precalculated trajectory has then to be compensated for both the range and the crossrange displacements, in order to have the re-entry body impact with the most probable accuracy. This compensation is achieved by proper presettings in the range computers of the guidance system on board the rocket.

The atmospheric temperature conditions are effective on the rocket trajectory mainly in terms of the Mach number, which, in turn, greatly affects the drag coefficient.

The wind profiles and density- and temperature-deviation profiles to be utilized for these compensations of the impact displacements will most likely be the climatological means. Much better results would be achieved with characteristic mean profiles, because of "historically" more realistic mean values, and consequently smaller dispersions (Sections II. A. 1 and II. A. 5). The most accurate displacement corrections would, of course, be obtained with individual, local radiosonde-data profiles, at the time of the rocket firing. However, these are rarely available for the impact area.

With this method of impact compensation of atmospheric effects on re-entry bodies, it has been determined that the impact accuracy of a ballistic rocket with 2800 kilometer ballistic range was improved by 40 to 60 percent of its error range without atmospheric compensation.

The rocket weight is also involved in wind and density conditions, since, eventually, a propellant reserve has to be planned for an extended propulsion phase caused by prevailing head winds or an atmosphere denser than the standard.

2. <u>Atmospheric Aspects of Rocket Flight Safety.</u> At the time of the actual rocket firing, the atmospheric conditions physically effective on the firing range have to be inserted into a check on the performance within established safety margins (Table XVIII). Included in the necessary safety parameters are those affected by wind and windshear conditions, as the allowable structural load on the rocket shell, the operational margin of the control and guidance systems, and the general aerodynamic stability margins. As an example, the launching of the first satellite of the Free World, Explorer 1, was postponed for almost 24 hours because of severe wind conditions (jet stream) above Cape Canaveral, Florida.

Another atmospheric parameter whose safety margin has to be checked is represented by hydrometeors, with regard to general precipitation conditions, icing conditions, visibility conditions for optical tracking of the rocket flight path, and precipitation noise for radar tracking of the rocket trajectory.

At the launching site proper, some atmospheric "operational environments" have to be observed in order to guarantee both a safe lift-off and a proper flight performance of the rocket. Thus, ambient temperature data enter into the propellant performance. In connection with the atmospheric temperature, surface winds affect the heat transfer coefficient, and determine to a noticable degree the prelaunching evaporation losses of lox.

Surface winds and gusts also affect the static, prelaunching stability of the rocket, and its initial, or lift-off stability. Because of the elastic properties of the rocket shell, concern exists about the forming of a v. Karman-vortex street on the lee-side of the erected rocket which might tumble down the rocket in case of structural resonance.

Visibility influences the accuracy of laying the rocket into the predetermined firing direction. As mentioned before, adequate visibility conditions are also essential for optical follow-up of the rocket flight path.

A very recent safety aspect of atmospheric operational environments shall be quoted for completeness sake. It is concerned with sound generation of the very large rocket engines of space boosters. The acoustic energy level of these gigantic engine assemblies (up to 10 million kilopond thrust) is so high (up to 125 million acoustic watt) that personnel at rocket experimentation stations, including launch sites, cannot be exposed to it, and structural damage to buildings has to be expected. At these excessively high acoustic energy levels, sound propagation has to be closely monitored, specifically with regard to actual aerological wind-, temperature-, and density-profiles, in order to avoid severe focusing effects of sound.

3. Atmospheric Analysis of Rocket Flight Performance. After explaining in detail the ballistic significance of atmospheric parameters under the topics of "Rocket Design Climatology" and "Atmospheric Rocket Physics", it appears self-evident that rocket launching installations have to be equipped to the optimum for providing all pertinent atmospheric information which is needed for the intricate evaluation and analysis of both exterior and interior ballistics of the rocket flight performance. In Table XIX, these parameters are quoted again for reference. These atmospheric measurements have to be performed through the whole spectrum of altitude ranges, starting with surface observations, passing through the radiosonde range, the meteorological rocket range, and, eventually, reaching into the orbital range of observational satellites.

Due to the necessary refinement in the ballistic flight analysis, the technical quality of the atmospheric soundings has to be of first rate. Intricate error analysis of presently-available measuring methods, particularly with radiosondes (Lenhard, Reference 33; Reisig, Reference 34) proves that these measuring techniques have to be improved substantially in order to match the advanced rocket technology of the present time. Especially, systematic errors should be eliminated, arising from the long flight time and the extended drift path of radiosondes which never can yield any instantaneous and strictly local atmospheric profile (Reisig, Reference 14). Thus, the rocket launching installations should be strong promoters of advanced atmospheric measuring techniques.

It is also self understood from the previous statements that a comprehensive aerological climatology should be available at every rocket launching installation. This type of climatology is still in its infancy, and even the aeroclimatology of Cape Canaveral, Florida, is still far from being complete. Particularly, any aeroclimatology in terms of characteristic profiles is simply not in existence at any rocket launching location. Again, the launching installations should take the lead in this important aspect of atmospheric ballistics.

## III. CONCLUSION

Concluding the elaborations on the role of atmospheric physics in rocket technology, it is believed that the atmospheric aspects of rocket engineering could be proven one of its fundamental components. Today's intricate rocket systems cannot be thought of without full respect to the numerous physical effects in the atmosphere.

Substantial basic work has been accomplished in the past decade of atmospheric ballistics. The main problems of atmospheric physics with respect to rocket performance could be formulated to a high degree of completion. The analytical approaches to many problems of atmospheric rocket physics could be established, but much numerical work remains to be done. The main objective of numerical programs in atmospheric ballistics is the establishment of advanced aerological climatologies. The most urgent topics of this promotion of aeroclimatology should be:

a. Presentation of climatological parameters in terms of characteristic profiles, as a particular mode of stratified or synoptic climatology.

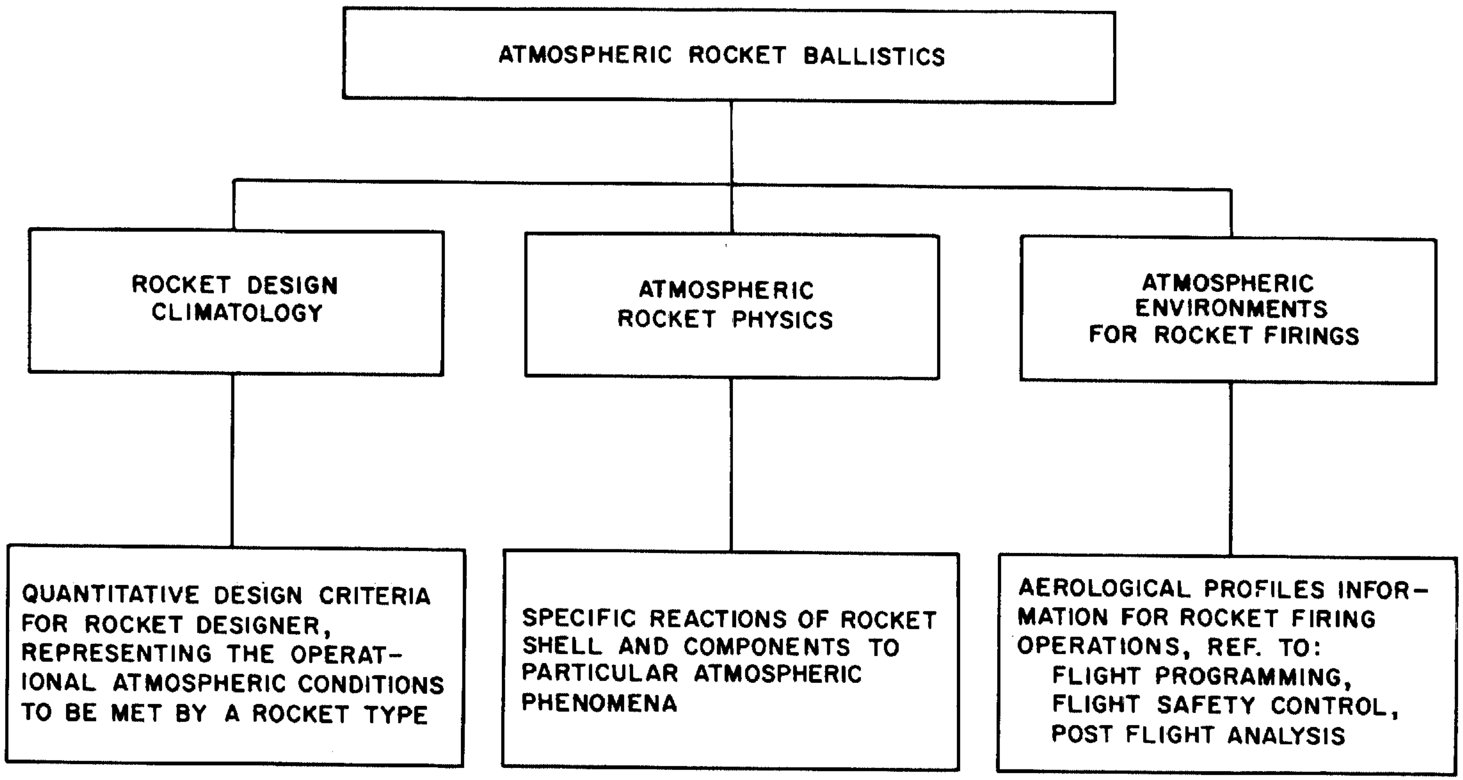
b. Advancing the climatological analysis, and establishment of frequency distributions, of less conventional atmospheric parameters, like wind shear, turbulence, and hydrometeors.

c. Establishment of true global, or at least hemispherical, climatologies of all discussed atmospheric parameters.

Again and again it has to be emphasized that frequent measurements in the free atmosphere are the key to new and badly-needed knowledge. The outcome of increased efforts under this topic should be the European sector of the synoptic meteorological rocket network (Faust, Reference 32). Parallel endeavor should be concerned with a substantial advancement of the art of atmospheric instrumentation. The present situation of sounding carriers being available without proper measuring equipment has to be improved drastically and rapidly.

Rocket men have postulated the atmospheric problems in ballistic terms. Meteorologists now are expected to join the team with their abundance of atmospheric experience, but realizing the ballistic peculiarities of rockets flying in the atmosphere.

TABLE I — AREAS OF ATMOSPHERIC ROCKET BALLISTICS



| TABLE II | BRANCHES OF ROCKET DESIGN CLIMATOLOGY |
|---|---|

- II.A. ROCKET DESIGN CLIMATOLOGY
  - II.A1 WIND CLIMATOLOGY
  - II.A2 WIND SHEAR CLIMATOLOGY
  - II.A3 TURBULENCE AND GUSTINESS CLIMATOLOGY
  - II.A4 DENSITY CLIMATOLOGY
  - II.A5 PRESSURE CLIMATOLOGY
  - II.A6 TEMPERATURE CLIMATOLOGY
  - II.A7 HYDROMETEOR CLIMATOLOGY
  - II.A8 RADIATION CLIMATOLOGY

| TABLE III | ROCKET APPLICATION OF WIND CLIMATOLOGY |
|---|---|

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT | |
|---|---|---|
| | BALLISTIC PARAMETER | ANALYTICAL TERMS |
| WIND SPEED (AVERAGE WIND SPEED PROFILE) | ANGLE OF ATTACK | $\alpha \approx \frac{W}{(V_g \mp W)}$ |
| | ATTITUDE ANGLE OF ROCKET AXIS | $\phi = f(W)$ |
| | LATERAL ACCELERATION OF ROCKET C. G. | $A_L = f(W)$ |
| | DYNAMIC PRESSURE | $Q = \frac{\rho \cdot (V_g \mp W)^2}{2}$ |
| | MACH NUMBER | $Ma = \frac{(V_g \mp W)}{\sqrt{\gamma \cdot R \cdot T_a}}$ |
| | REYNOLDS NUMBER | $Re = \frac{(V_g \mp W) \cdot \eta \cdot L}{\rho}$ |

$\alpha$ ≙ ANGLE OF ATTACK
$\gamma$ ≙ RATIO OF SPECIFIC HEATS
$\eta$ ≙ VISCOSITY
$\rho$ ≙ ATMOSPHERIC DENSITY
$\phi$ ≙ ATTITUDE ANGLE
$A_L$ ≙ LATERAL ACCELERATION
L ≙ CHARACTERISTIC LENGTH
Ma ≙ MACH NUMBER
Q ≙ DYNAMIC PRESSURE
R ≙ GAS CONSTANT
Re ≙ REYNOLDS NUMBER
$T_a$ ≙ AMBIENT TEMPERATURE
$V_g$ ≙ GEOMETRIC VELOCITY OF BODY
W ≙ WIND SPEED

## TABLE - IV A — STATIONS OF AMC CLIMATOLOGICAL RINGBOOK
STATUS: 1 SEPTEMBER 1962

| EUROPE & NORTH AFRICA | | | | | EUROPE & NORTH AFRICA | | | | |
|---|---|---|---|---|---|---|---|---|---|
| STATION | COUNTRY | WIND | THERMODYNAMICS | DATA PREPARATION | STATION | COUNTRY | WIND | THERMODYNAMICS | DATA PREPARATION |
| ATHENS | GREECE | O | O | S | NICOSIA | CYPRUS | O | O | S |
| BEOGRAD | YUGOSLAVIA | O | O | S | PARIS | FRANCE | O | O | S |
| BERLIN | GERMANY | ● | O | N S | PETROZAVODSK | USSR | O | O | S |
| BREST | USSR | O | O | S | PORT LYAUTEY | MAROCCO | ● | — | N |
| CHERNOVITZI | USSR | O | O | S | RIGA | USSR | O | O | S |
| EMDEM | GERMANY | O | O | D | SCHLESWIG | GERMANY | O | O | D |
| HANNOVER | GERMANY | O | O | D | SMOLENSK | USSR | O | O | S |
| JAN MAYEN | NORWAY | O | O | S | SODANKYLÄ | FINLAND | O | O | S |
| KEFLAVIK | ICELAND | ● | O | N S | SORTEVALA | USSR | O | O | S |
| KYEV | USSR | O | O | S | STOCKHOLM | SWEDEN | O | O | S |
| LERWICK | UK (SHETLAND IS.) | O | O | S | STUTTGART | GERMANY | O | O | D |
| LIVERPOOL | UK | O | O | S | TRIPOLIS | LYBIA | ● | ● | N |
| MOSCOW | USSR | O | O | S | WIEN | AUSTRIA | O | ● | S N |
| MUENCHEN | GERMANY | O | O | S | WIESBADEN | GERMANY | ● | ● | N |

LEGEND:

D ≙ DEUTSCHER WETTERDIENST
N ≙ U. S. NATIONAL WEATHER RECORDS CENTER
S ≙ FREE UNIVERSITY OF BERLIN (GERMANY) (PROF. SCHERHAG)
● ≙ FREQUENCY DISTRIBUTIONS PUBLISHED
O ≙ RAW DATA PREPARED

## TABLE IV B — STATIONS OF AMC CLIMATOLOGICAL RINGBOOK STATUS: 1 SEPTEMBER 1962

| NORTH AMERICA AND FAR EAST | | WIND | THERMODYNAMICS | DATA PREPARATION | NORTH AMERICA AND FAR EAST | | WIND | THERMODYNAMICS | DATA PREPARATION |
|---|---|---|---|---|---|---|---|---|---|
| STATION | COUNTRY | | | | STATION | COUNTRY | | | |
| ADAK, ALASKA | USA | ● | O | N | INTERNATIONAL FALLS MINNESOTA | USA | ● | — | N |
| ALBROOK | PANAMA CANAL ZONE | O | O | N | JOHNSTON ISLAND | PACIFIC (USA) | O | — | N |
| ALERT | CANADA | ● | — | N S | LIHUE, HAWAII | USA | O | O | N |
| BARROW, ALASKA | USA | ● | — | N | LUZON | PHILLIPINES | O | O | N |
| CAPE CANAVERAL, FLORIDA | USA | ● | ● | N | SAN JUAN | PUERTO RICO | O | O | N |
| EL PASO, TEXAS | USA | O | ● | N | SANTA MARIA, CALIFORNIA | USA | O | — | N |
| FAIRBANKS, ALASKA | USA | ● | ● | N | SILVERHILL, MARYLAND | USA | O | — | N |
| GRAND BAHAMA ISLAND | WEST INDIES (UK) | O | — | N | THULE, GREENLAND | DENMARK | ● | ● | N |
| GREENLAND /NORTH | DENMARK | O | O | S | TOKYO /NAGOYA | JAPAN | ● | — | N |
| GUAM | USA | O | O | N | | | | | |

LEGEND:

D ≙ DEUTSCHER WETTERDIENST
N ≙ U. S. NATIONAL WEATHER RECORDS CENTER
S ≙ FREE UNIVERSITY OF BERLIN (GERMANY) (PROF. SCHERHAG)
● ≙ FREQUENCY DISTRIBUTIONS PUBLISHED
O ≙ RAW DATA PREPARED

## TABLE V — ROCKET APPLICATION OF WIND SHEAR CLIMATOLOGY

| ATMOSPHERIC PARAMETER | BALISTIC EFFECT | |
|---|---|---|
| | BALISTIC PARAMETER | ANALYTICAL TERMS |
| WIND SHEAR (SLOPE OF AVERAGE WIND SPEED PROFILE) | ANGLE OF ATTACK INCREMENT | $\Delta\alpha = \frac{\Delta W}{V_a}(1-\alpha) \approx \frac{\Delta W}{V_a}$ <br> $(V_a = V_g \hat{\mp} W)$ |
| | ANGULAR VELOCITY OF ROCKET AXIS | $\frac{d\phi}{dT} = f\left(\frac{d\alpha}{dT}\right) = f\,(\Delta W)$ |
| | CHANGE OF LATERAL ACCELERATION | $\frac{dA_L}{dT} = f\,(\Delta W)$ |
| | NONSTATIONARY AERODYNAMIC MOMENT | $\Delta M = \frac{\partial C_{N_\alpha}}{\partial\alpha} \cdot \Delta W \cdot (V_g \hat{\mp} W) \cdot \frac{\rho}{2} \cdot L \cdot S$ |
| | SCALE OF DISTANCE | $WS = \frac{\Delta W}{\Delta H} = f\,(SOD)$ |

$\alpha$ ≙ ANGLE OF ATTACK
$\rho$ ≙ ATMOSPHERIC DENSITY
$\phi$ ≙ ATTITUDE ANGLE
$A_L$ ≙ LATERAL ACCELERATION
$C_{N_\alpha}$ ≙ AERODYNAMIC MOMENT COEFFICIENT
H ≙ HEIGHT
L ≙ CHARACTERISTIC LENGTH
S ≙ CROSS-SECTIONAL AREA
SOD ≙ SCALE OF DISTANCE
T ≙ TIME
$V_a$ ≙ AIR FLOW VELOCITY
$V_g$ ≙ GEOMETRIC VELOCITY OF BODY
W ≙ WIND SPEED

| TABLE VI | ROCKET APPLICATION OF TURBULENCE (GUSTINESS) CLIMATOLOGY |
|---|---|

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT | |
|---|---|---|
| | BALLISTIC PARAMETER | ANALYTICAL TERMS |
| TURBULENCE (GUSTS)<br><br>(SHORT DURATION WIND SPEED FLUCTUATIONS ABOUT AVERAGE WIND SPEED) | SCALE OF TURBULENCE (EDDY SIZE) | MIXING LENGTH $\lambda$ (PRANDTL) |
| | FREQUENCY OF EDDIES | $F = f(\delta W)$ |
| | ANGLE OF ATTACK INCREMENT | $\delta\alpha = \frac{\delta W}{V_a} \cdot (1-\alpha) \approx \frac{\delta W}{V_a}$<br>$V_a = V_g \hat{+} W$ |
| | ANGULAR ACCELERATIONS OF ROCKET AXIS | $\frac{d^2\phi}{dT^2} = f\left(\frac{d^2\alpha}{dT^2}\right) = f(\delta W)$ |
| | NONSTATIONARY AERODYNAMIC MOMENT | $\delta M = \frac{\partial C_{N_\alpha}}{\partial \alpha} \cdot \delta W \cdot (V_g \hat{+} W) \cdot \frac{\rho}{2} \cdot L \cdot S$ |

| | | | |
|---|---|---|---|
| $\alpha$ | ≙ ANGLE OF ATTACK | $F$ | ≙ FREQUENCY |
| $\delta$ | ≙ "SHORT DURATION" DIFFERENTIAL | $L$ | ≙ CHARACTERISTIC LENGTH |
| $\lambda$ | ≙ MIXING LENGTH | $S$ | ≙ REFERENCE AREA |
| $\rho$ | ≙ ATMOSPHERIC DENSITY | $T$ | ≙ TIME |
| $\phi$ | ≙ ATTITUDE ANGLE | $V_a$ | ≙ AIR FLOW VELOCITY |
| $C_{N_\alpha}$ | ≙ AERODYNAMIC MOMENT COEFFICIENT | $V_g$ | ≙ GEOMETRIC VELOCITY OF BODY |
| | | $W$ | ≙ WIND SPEED |

## TABLE VII — ROCKET APPLICATION OF DENSITY CLIMATOLOGY

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT | |
|---|---|---|
| | BALLISTIC PARAMETER | ANALYTICAL TERMS |
| ATMOSPHERIC DENSITY (REFERENCE: ARDC- MODEL ATMOSPHERE) | DYNAMIC PRESSURE | $Q = \frac{\rho \cdot V_a^2}{2}$ → LIFT: $A = C_L \cdot Q \cdot S$; DRAG: $D = C_D \cdot Q \cdot S$; FORCE: $F = C_F \cdot Q \cdot S$ |
| | REYNOLDS NUMBER | $Re = \frac{\rho \cdot V_a \cdot S}{\eta}$ |
| | PRANDTL NUMBER | $Pr = \frac{\eta}{\rho \cdot k}$ |

$\eta$ ≙ VISCOSITY
$\rho$ ≙ AIR DENSITY
$A$ ≙ AERODYNAMIC LIFT
$C_D$ ≙ DRAG COEFFICIENT
$C_F$ ≙ FORCE COEFFICIENT
$C_L$ ≙ LIFT COEFFICIENT
$D$ ≙ DRAG
$F$ ≙ AERODYNAMIC FORCE
$k$ ≙ THERMAL CONDUCTIVITY
$L$ ≙ REFERENCE LENGTH
$Pr$ ≙ PRANDTL NUMBER
$Q$ ≙ DYNAMIC PRESSURE
$Re$ ≙ REYNOLDS NUMBER
$S$ ≙ REFERENCE AREA
$V_a$ ≙ AIR FLOW VELOCITY

## TABLE VIII — ROCKET APPLICATION OF PRESSURE CLIMATOLOGY

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT: BALLISTIC PARAMETER | BALLISTIC EFFECT: ANALYTICAL TERMS |
|---|---|---|
| ATMOSPHERIC PRESSURE | PRESSURE DISTRIBUTION AROUND BODY SURFACES | $\frac{\Delta P}{Q} = \frac{P_s - P_a}{Q} = C_P$ |
| | BASE DRAG | $D_B = C_{DB} \cdot Q \cdot S,\quad C_{DB} = \frac{P_B - P_a}{Q} \cdot \frac{S_B}{S}$ |
| | THRUST GAIN | $G_F = (P_{ex} - P_a) \cdot S_{ex} \cdot \eta$ |
| | DENSITY DETERMINATION | $\rho = \frac{P_a}{R \cdot T_a}$ *) |

$\eta$ ≙ THRUST EFFICIENCY COEFFICIENT
$\rho$ ≙ AIR DENSITY
$C_{DB}$ ≙ BASE DRAG COEFFICIENT
$C_P$ ≙ PRESSURE COEFFICIENT
$D_B$ ≙ BASE DRAG
$G_F$ ≙ THRUST GAIN
$P_a$ ≙ ATMOSPHERIC PRESSURE
$P_B$ ≙ BASE PRESSURE
$P_{ex}$ ≙ NOZZLE EXIT PRESSURE
$P_s$ ≙ SURFACE PRESSURE
$Q$ ≙ DYNAMIC PRESSURE
$R$ ≙ GAS CONSTANT
$S$ ≙ REFERENCE AREA
$S_B$ ≙ BASE AREA
$S_{ex}$ ≙ NOZZLE EXIT AREA
$T_a$ ≙ ATMOSPHERIC TEMPERATURE
*) EQUATION OF STATE OF GAS

| TABLE IX | ROCKET APPLICATION OF TEMPERATURE CLIMATOLOGY |
|---|---|

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT | | |
|---|---|---|---|
| | BALLISTIC PARAMETER | ANALYTICAL TERMS | |
| ATMOSPHERIC TEMPERATURE | DENSITY DETERMINATION | $\rho = \frac{P_a}{R \cdot T_a}$ | *) |
| | MACH NUMBER | $Ma = \frac{V_a}{\sqrt{\gamma \cdot R \cdot T_a}}$ | |
| | REYNOLDS NUMBER | $Re = \frac{\rho(T_a) \cdot V_a \cdot L}{\eta(T_a)}$ | |
| | PRANDTL NUMBER | $Pr = \frac{\eta(T_a)}{\rho(T_a) \cdot K}$ | |
| | DRAG COEFFICIENT | $C_D = f(Ma; Re; Pr) = f(T_a)$ | |
| | AERODYNAMIC HEATING | $T_t = T_a \left(1 + \frac{(\gamma - 1)}{2} Ma^2\right)$ | |

$\gamma$ ≙ RATIO OF SPECIFIC HEATS
$\eta$ ≙ VISCOSITY
$\rho$ ≙ AIR DENSITY
$C_D$ ≙ DRAG COEFFICIENT
K ≙ THERMAL CONDUCTIVITY
L ≙ REFERENCE LENGTH
Ma ≙ MACH NUMBER
$P_a$ ≙ ATMOSPHERIC PRESSURE
Pr ≙ PRANDTL NUMBER
R ≙ GAS CONSTANT
Re ≙ REYNOLDS NUMBER
$T_a$ ≙ ATMOSPHERIC TEMPERATURE
$T_t$ ≙ TOTAL TEMPERATURE
$V_a$ ≙ AIR FLOW VELOCITY
*) EQUATION OF STATE OF GAS

# TABLE X — ROCKET APPLICATION OF HYDROMETEOR CLIMATOLOGY

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT | |
|---|---|---|
| | BALLISTIC PARAMETER | ANALYTICAL TERMS |
| HYDROMETEORS<br>(RAINDROPS<br>CLOUDDROPS<br>SNOWFLAKES<br>SLEET<br>ICE CRYSTALS<br>GRAUPEL<br>HAILSTONES) | STRUCTURAL STRENGTH OF ROCKET SHELL | FREQUENCY OF OCCURRENCE OF HYDROMETEORS VS. WEATHER SITUATIONS: $P_{HM} = f(H;T)$ |
| | AERODYNAMIC PROFILE MODIFICATIONS FROM ADHERING HYDROMETEORS | MOMENTUM DISTRIBUTION OF HYDROMETEORS: $I = M \cdot V$, $P_I = f(H;T)$ |
| | INSTRUMENT CLOGGING | SIZE DISTRIBUTION OF HYDROMETEORS: $P_S = f(H;T)$ |

H $\hat{=}$ ALTITUDE

I $\hat{=}$ MOMENTUM

M $\hat{=}$ MASS

$P_{HM}$ $\hat{=}$ FREQUENCY OF OCCURRENCE OF HYDROMETEORS

$P_I$ $\hat{=}$ FREQUENCY OF OCCURRENCE OF MOMENTUM CLASSES OF HYDROMETEORS

$P_S$ $\hat{=}$ FREQUENCY OF OCCURRENCE OF SIZE CLASSES OF HYDROMETEORS

T $\hat{=}$ TIME

V $\hat{=}$ FLOW VELOCITY

TABLE XI ROCKET APPLICATION OF RADIATION CLIMATOLOGY

| ATMOSPHERIC PARAMETER | BALLISTIC EFFECT |
|---|---|
| ATMOSPHERIC RADIATION<br>(INFRARED<br>VISIBLE LIGHT<br>ULTRAVIOLET<br>COSMIC RAY<br>NUCLEAR<br>GAMMA) | STRUCTURAL STRENGTH<br>INSTRUMENT "CLOGGING" |

TABLE XII ATMOSPHERIC ROCKET BALLISTICS
2 ATMOSPHERIC ROCKET PHYSICS

- II.B ATMOSPHERIC ROCKET PHYSICS
  - II.B.1 TURBULENCE (GUST) DYNAMICS
  - II.B.2 HYDROMETEOR IMPACTS
  - II.B.3 RAREFIED GAS PHYSICS
  - II.B.4 EXPLORATION OF IGNOSPHERE

## TABLE XIII ATMOSPHERIC TURBULENCE (GUST) DYNAMICS

| ATMOSPHERIC PHENOMENA | ANALYSIS |
|---|---|
| **FREE ATMOSPHERE MEASUREMENTS**<br><br>WIND SPEED<br>WIND DIRECTION<br>WIND SHEAR<br>WIND GRADIENT<br><br>WIND SPEED FLUCTUATIONS<br>VAPOR TRAIL DISPERSION<br>CHAFF DISPERSION<br>BALLOON DROP PATH | **ATMOSPHERIC TURBULENCE CHARACTERISTICS**<br>FROM TYPICAL FEATURES OF CHARACTERISTIC WIND SPEED /WIND SHEAR PROFILES |
| | **SPECTRAL ANALYSIS OF ATMOSPHERIC TURBULENCE**<br>EDDY SIZES<br>MIXING LENGTHS<br>WAVE LENGTHS<br>EDDY INTENSITIES |
| | **STATISTICS**<br>OF ATMOSPHERIC FLOW-FLUCTUATION DATA |
| | **ATMOSPHERIC TURBULENCE MODEL**<br>EDDY FORMATION AND DISSIPATION IN ATMOSPHERIC SHEAR FLOW |

**TABLE XIV** — HYDROMETEOR IMPACT DYNAMICS

| ATMOSPHERIC PHENOMENA | ANALYSIS |
|---|---|
| **HYDROMETEOR INTERACTION**<br>WITH SHOCK WAVES | **WIND TUNNEL TESTS**<br>**BALLISTIC RANGE TESTS**<br>WITH HYDROMETEOR "SPRAY" |
| **TRAJECTORIES OF HYDROMETEORS**<br>AROUND ROCKET SHELLS (NOSE CONE) | |
| **AERODYNAMIC MODIFICATION**<br>OF ROCKET SHELLS (COAGULATION OF HYDROMETEORS) | **AERODYNAMICAL ANALYSIS** |
| **FREE ATMOSPHERE MEASUREMENTS**<br>APPLYING: MICROPHONE<br>MUSHROOM-SONDE (JAPAN)<br>ICING GAGE<br>CONTACT COUNTER<br>OPTICAL COUNTER | **STATISTICS**<br>OF HYDROMETEOR FLIGHT MEASUREMENTS |

## TABLE XV — ATMOSPHERIC RAREFIED GAS PHYSICS

| ATMOSPHERIC PHENOMENA | ANALYSIS |
|---|---|
| RAREFIED GAS FLOW | KNUDSEN NUMBER: $Kn = \frac{\lambda}{L} \approx \frac{Ma}{Re}$ |
| SLIP-FLOW REGIME | $0.01 < Kn < 0.1$<br>$Kn \approx \frac{Ma}{Re}$; $Re < 1$<br>$Kn \approx \frac{Ma}{\sqrt{Re}}$; $Re > 1$ |
| TRANSITION-FLOW REGIME | $0.1 < Kn < 10$ |
| FREE MOLECULE-FLOW REGIME | $Kn > 10$<br>$r > 1$<br>$r = \frac{T_w - T_a}{T_t - T_a}$ |

$\lambda$ ≙ MEAN FREE PATH OF MOLECULE

$Kn$ ≙ KNUDSEN NUMBER

$L$ ≙ CHARACTERISTIC LENGTH

$Ma$ ≙ MACH NUMBER

$r$ ≙ RECOVERY FACTOR

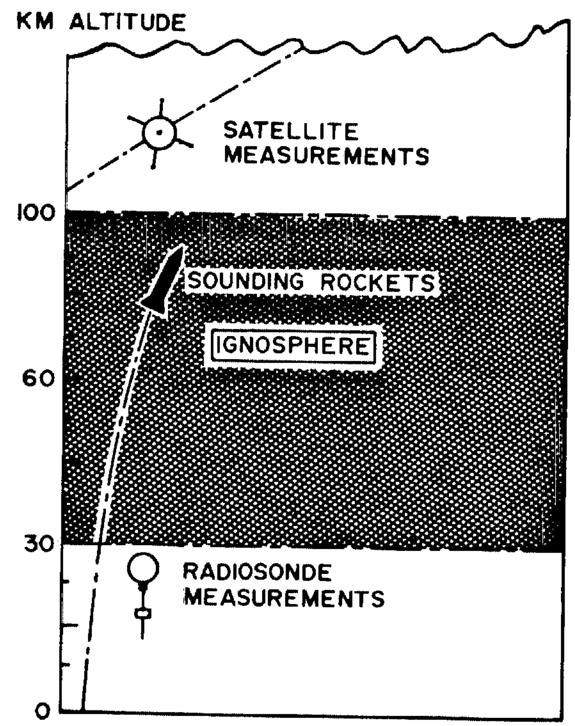
$Re$ ≙ REYNOLDS NUMBER

$T_a$ ≙ AMBIENT TEMPERATURE

$T_t$ ≙ TOTAL TEMPERATURE

$T_w$ ≙ WALL TEMPERATURE

# TABLE XVI EXPLORATION OF IGNOSPHERE

| PHENOMENOLOGICAL SITUATION | NECESSARY ACTIVITIES |
|---|---|
|  | UPPER ATMOSPHERE MEASUREMENTS<br>SYNOPTIC METEOROLOGICAL ROCKET NETWORK<br>SOPHISTICATED SOUNDING ROCKETS |
| | ATMOSPHERIC STATISTICS<br>TIE-IN WITH RADIOSONDE AND SATELLITE ATMOSPHERIC DATA<br>"IGNOSPHERE CLIMATOLOGY" |
| | SYNTHESIS OF DYNAMIC MODEL OF WHOLE ATMOSPHERE |

## TABLE XVII — ATMOSPHERIC ASPECTS OF ROCKET FLIGHT PROGRAMMING

| ATMOSPHERIC BALLISTICS TOPICS | ATMOSPHERIC INFORMATION NEEDED |
|---|---|
| **ROCKET STABILITY**<br>SECURING OF: (A) CONTROL RANGE OF CONTROL-& GUIDANCE-SYSTEM<br>(B) NATURAL AERODYNAMIC STABILITY RANGE OF BODY<br><br>FOR EFFECTS OF:<br>WIND SPEED<br>WIND SHEAR<br>GUSTS<br>HYDROMETEOR AGGLOMERATION | LOCAL AEROLOGICAL CLIMATOLOGY<br>PROFILES OF HIGH FREQUENCY OF OCCURRENCE |
| **ROCKET TRAJECTORY PRECALCULATION**<br>(A) TRAJECTORY INTEGRATION<br>WITH: STANDARD DENSITY PROFILE<br>STANDARD PRESSURE PROFILE<br>STANDARD TEMPERATURE PROFILE<br>ZERO WIND SPEED<br><br>(B) COMPENSATION OF IMPACT DISPLACEMENT<br>DUE TO: WIND SPEED<br>DENSITY DEVIATIONS FROM STANDARD ATMOSPHERE<br>TEMPERATURE DEVIATIONS FROM STANDARD ATMOSPHERE | STANDARD ATMOSPHERE PROFILES<br>(ARDC MODEL ATMOSPHERE)<br>MEAN PROFILES<br><br>LOCAL AEROLOGICAL CLIMATOLOGY<br>MEAN PROFILES<br>CHARACTERISTIC PROFILES<br><br>LOCAL RADIOSONDE PROFILES |

## TABLE XVIII ATMOSPHERIC ASPECTS OF ROCKET FLIGHT SAFETY

1. ROCKET BALLISTIC SAFETY MARGIN WITH REGARD TO:

   A. WIND

      (1) SHELL STRUCTURAL LOAD
      (2) CONTROL MARGIN
      (3) GUIDANCE MARGIN
      (4) AERODYNAMIC STABILITY MARGIN

   B. WIND SHEAR/TURBULENCE

      (1) SHELL STRUCTURAL LOAD
      (2) AERODYNAMIC STABILITY MARGIN

   C. HYDROMETEORS

      STRUCTURAL STRENGTH

2. OPERATIONAL ENVIRONMENTS

   A. AMBIENT TEMPERATURE

   B. SURFACE WINDS AND GUSTS

   C. VISIBILITY

   D. SOUND PROPAGATION

TABLE XIX — ATMOSPHERIC REQUIREMENTS FOR ROCKET FLIGHT PERFORMANCE ANALYSIS

| ATMOSPHERIC PARAMETERS | INSTRUMENTATION |
|---|---|
| DENSITY | SURFACE STATION |
| HEAT RADIATION | METEOROLOGICAL TOWER |
| HUMIDITY | RADIOSONDE |
| HYDROMETEORS | METEOROLOGICAL ROCKET |
| PRECIPITATION | ATMOSPHERIC SOUNDING SATELLITE |
| PRESSURE | |
| REFRACTIVE INDEX | |
| TEMPERATURE | |
| TURBULENCE | |
| VELOCITY OF SOUND | |
| VISIBILITY | |
| WIND DIRECTION | |
| WIND SPEED | |

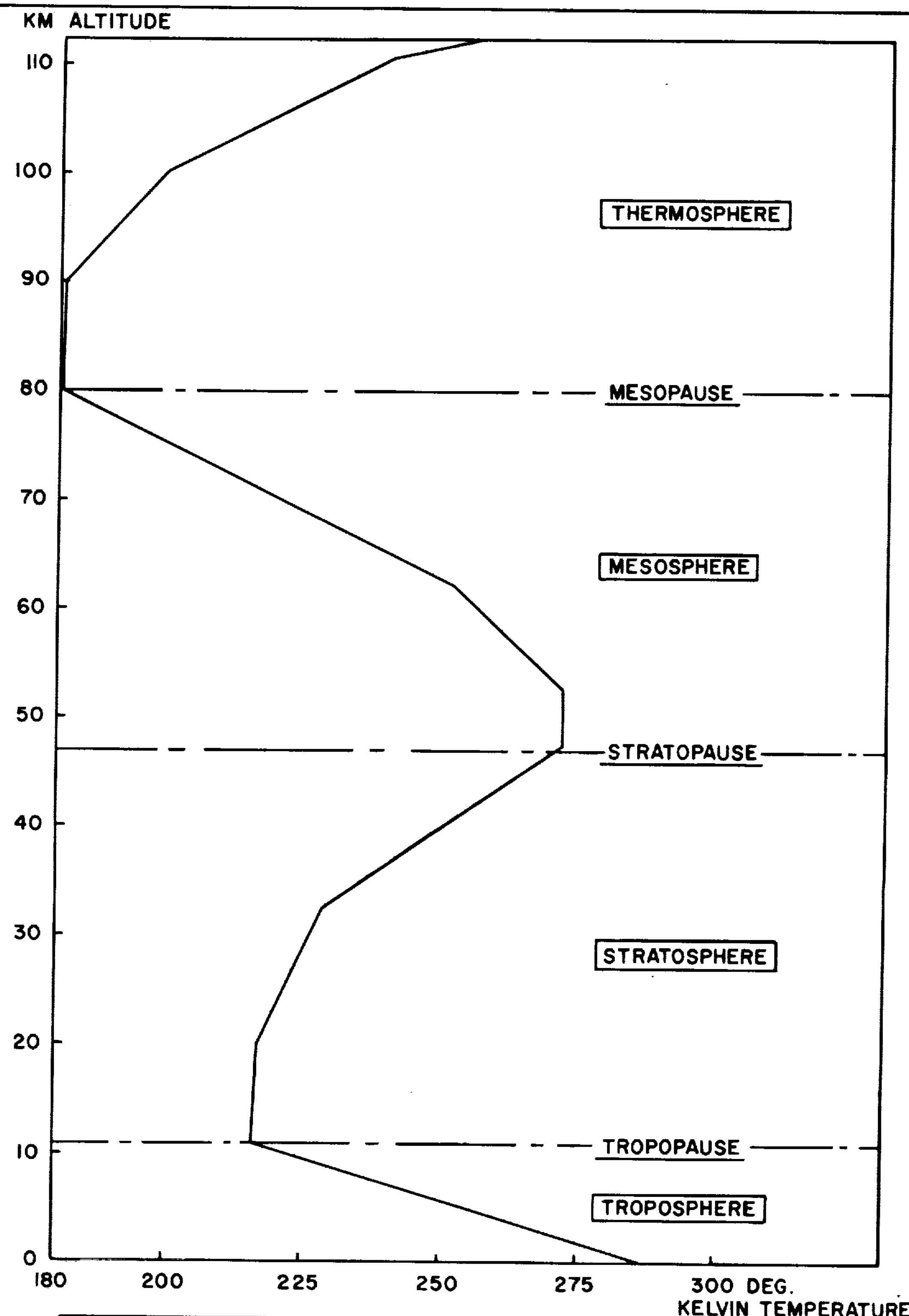
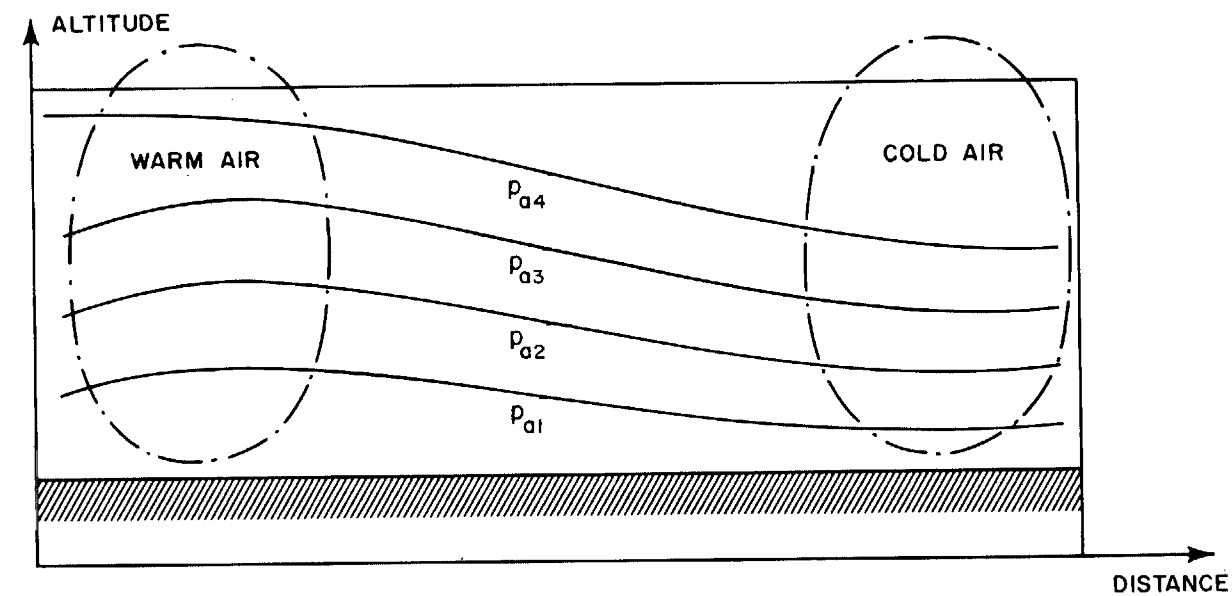



FIG. I LAYERS OF THE ATMOSPHERE ACCORDING TO AMBIENT TEMPERATURE PROFILE (AFTER: U. S. NAVY WEATH. RES. FAC.)




| FIG. 2 | HEIGHT VARIATION OF CONSTANT PRESSURE SURFACES WITH DISTANCE |
|---|---|

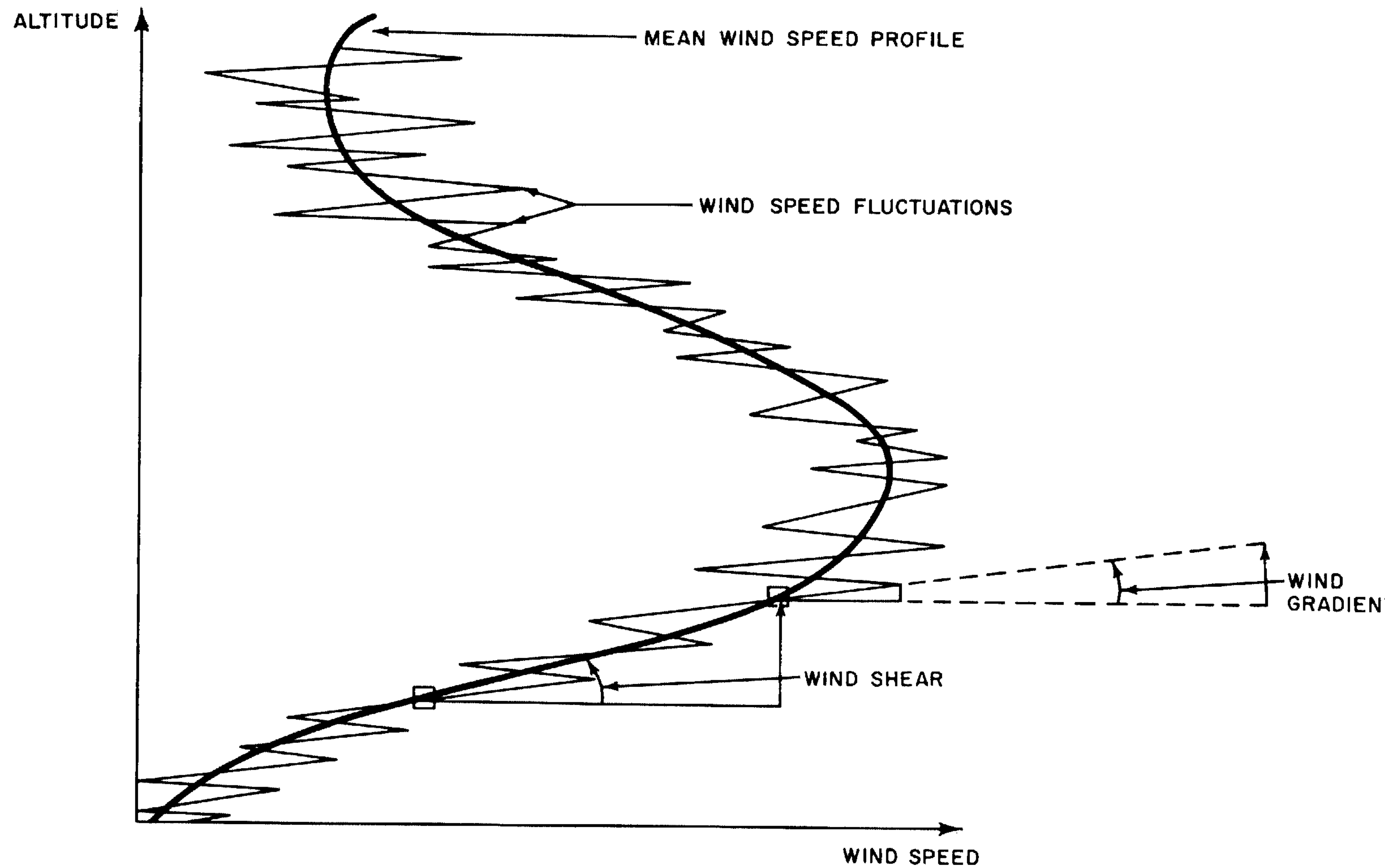



FIG. 3 DEFINITION OF WIND PARAMETERS

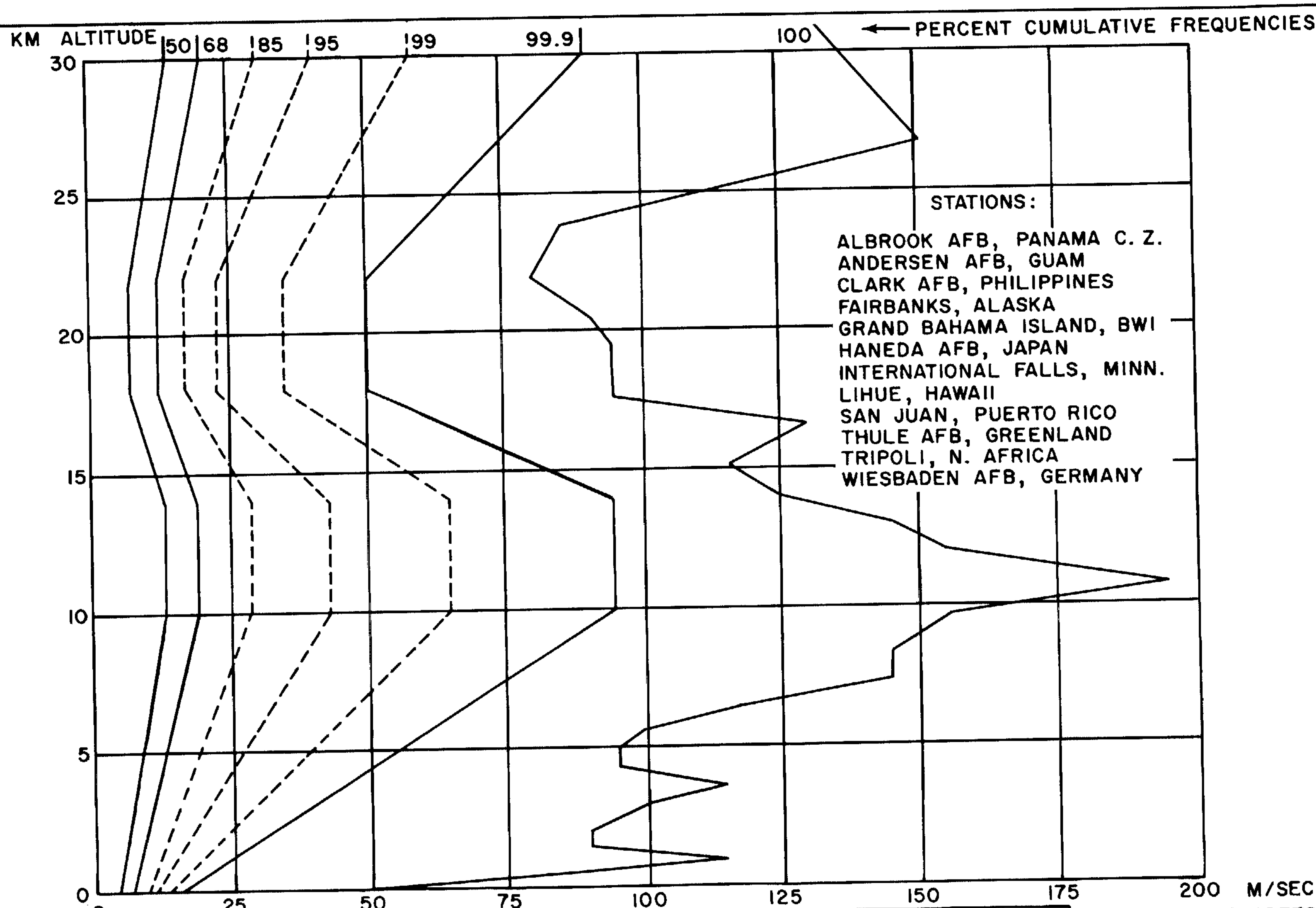



FIG. 4 GLOBAL WIND SPEED PROFILES (IDEALIZED) CUMULATIVE FREQUENCIES - 12 STATIONS

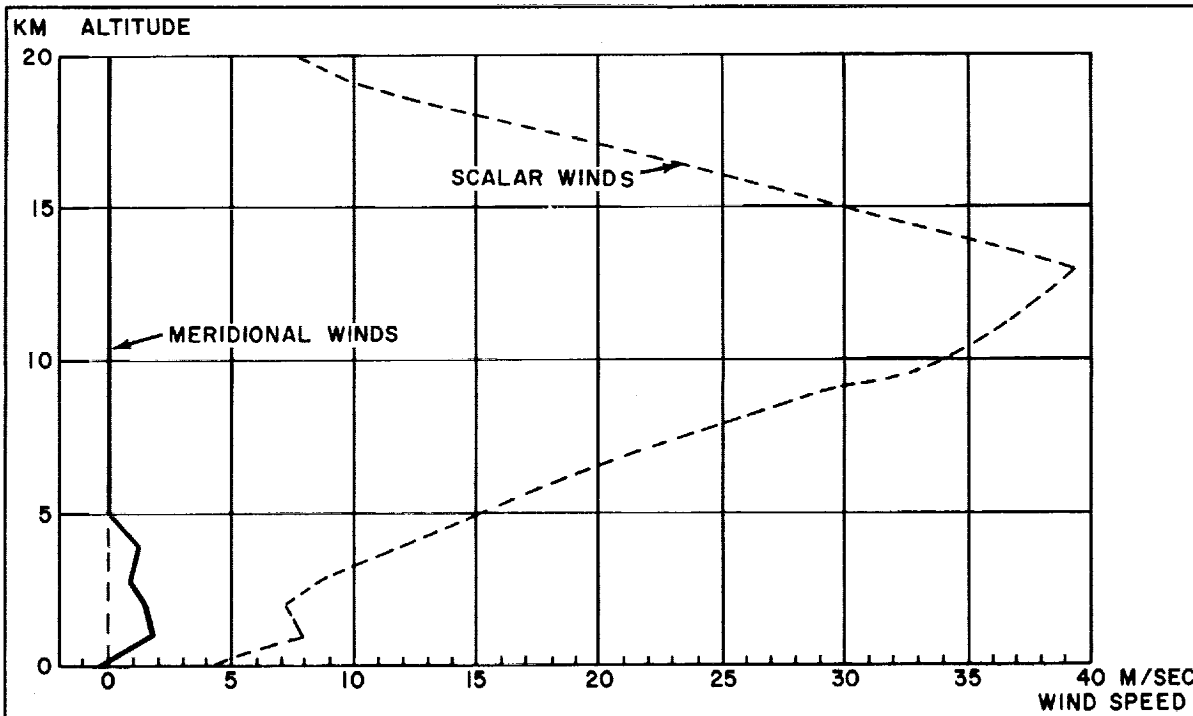



FIG. 5 MERIDIONAL AND SCALAR MEAN WIND SPEEDS CAPE CANAVERAL, DECEMBER

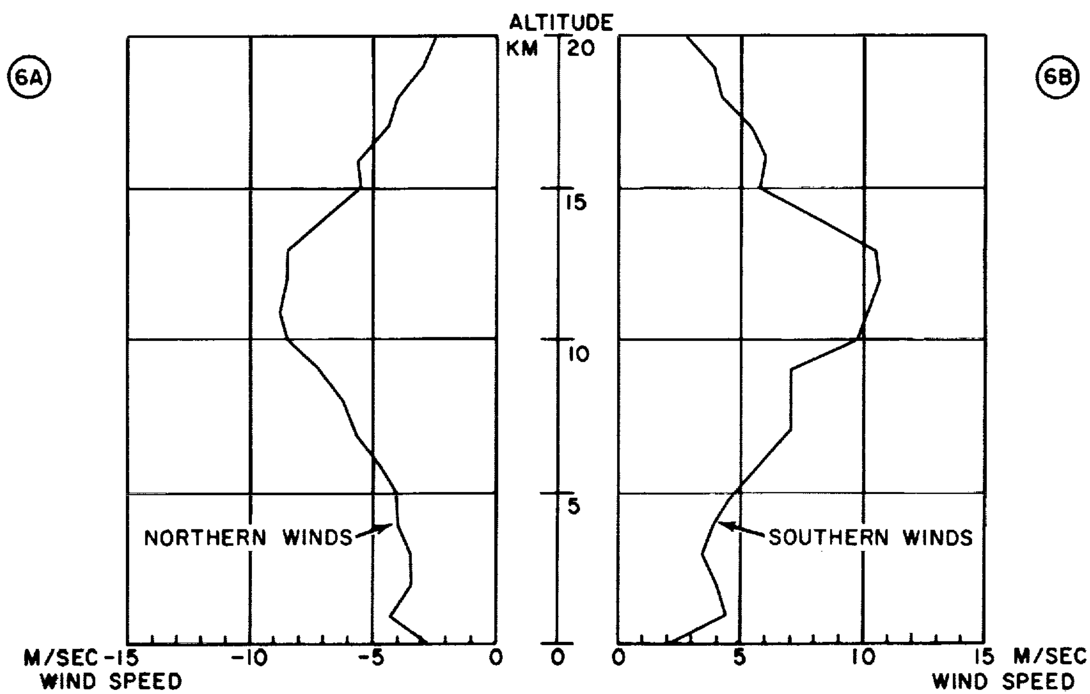
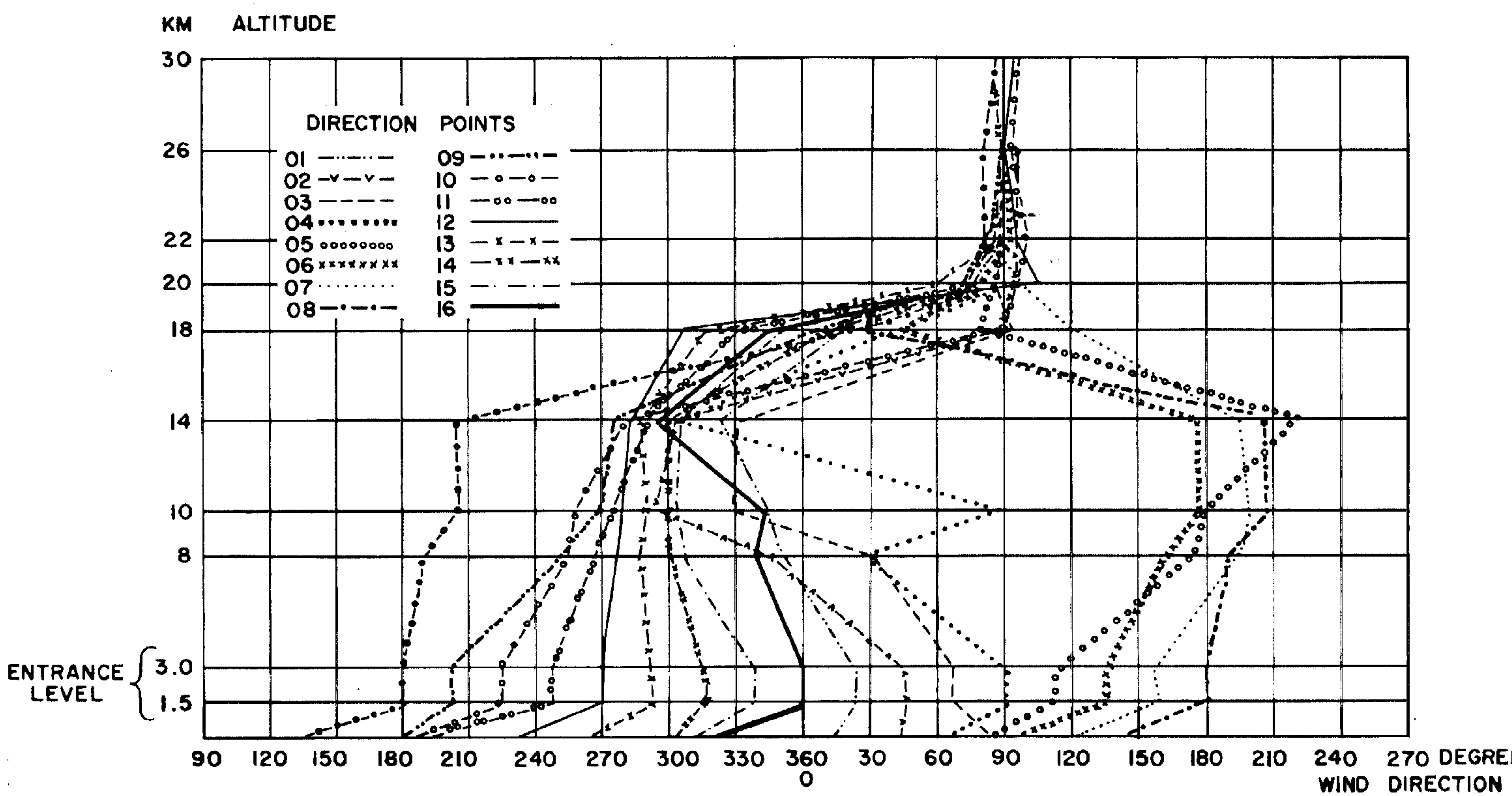
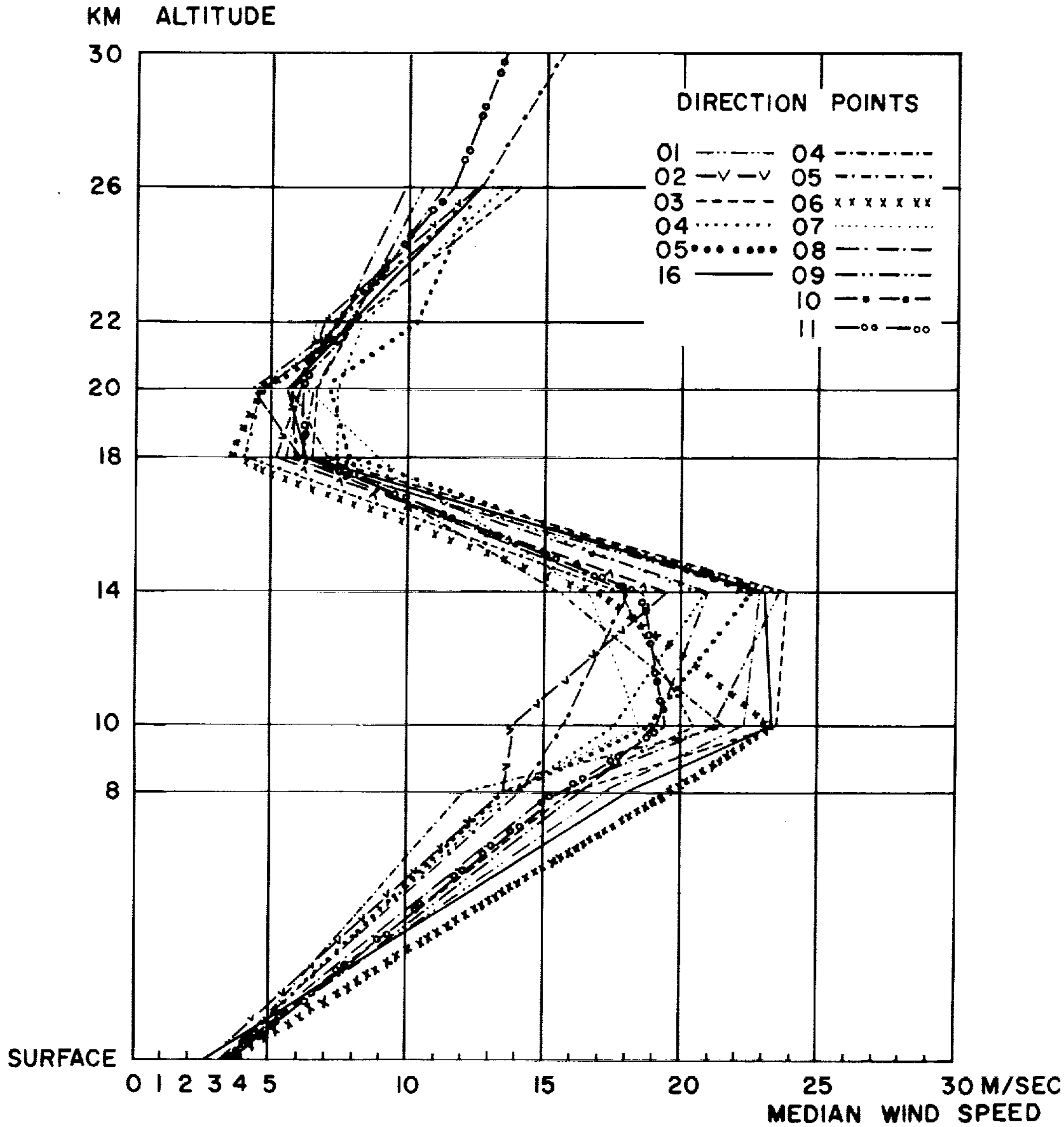



FIG. 6 SEMIPLANAR MEAN WIND SPEEDS CAPE CANAVERAL, DECEMBER




| | |
|---|---|
| FIG. 7 | MEAN WIND DIRECTION PROFILES<br>PER WEATHER SITUATION<br>REFERENCE: CONSTANT WIND DIRECTION AT<br>1500 TO 3000 METER ALTITUDE<br>WASHINGTON, D. C. /SUMMER (AFTER: ESSENWANGER) |




| FIG. 8 | MEDIAN WIND SPEED PROFILES<br>PER WEATHER SITUATION<br>REFERENCE: CONSTANT WIND DIRECTION AT<br>1500 TO 3000 METER ALTITUDE<br>WASHINGTON, D. C. /SUMMER (AFTER: ESSENWANGER) |
|---|---|

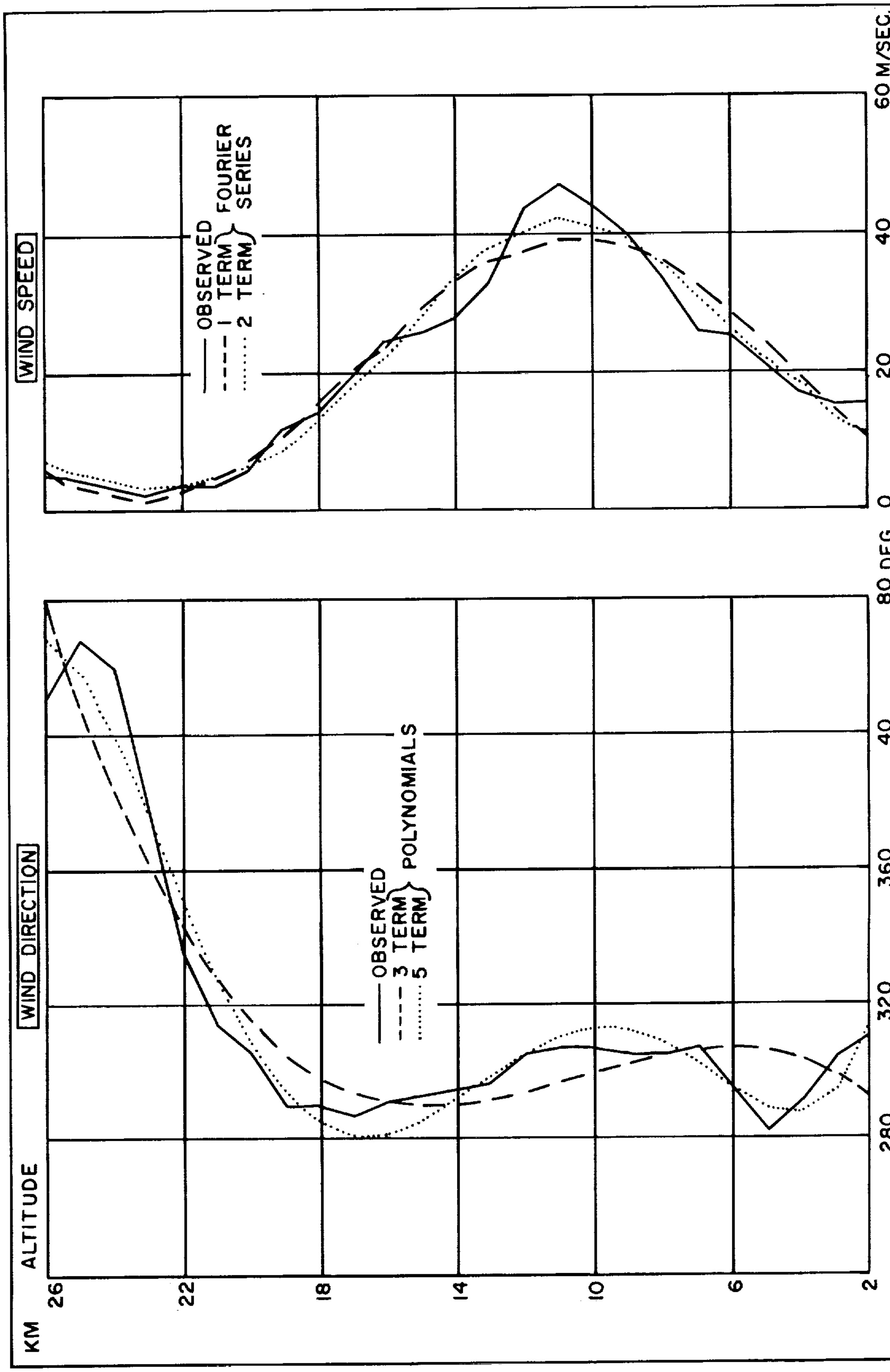



FIG. 9

MATHEMATICAL REPRESENTATION OF WIND PARAMETERS (AFTER: ESSENWANGER)

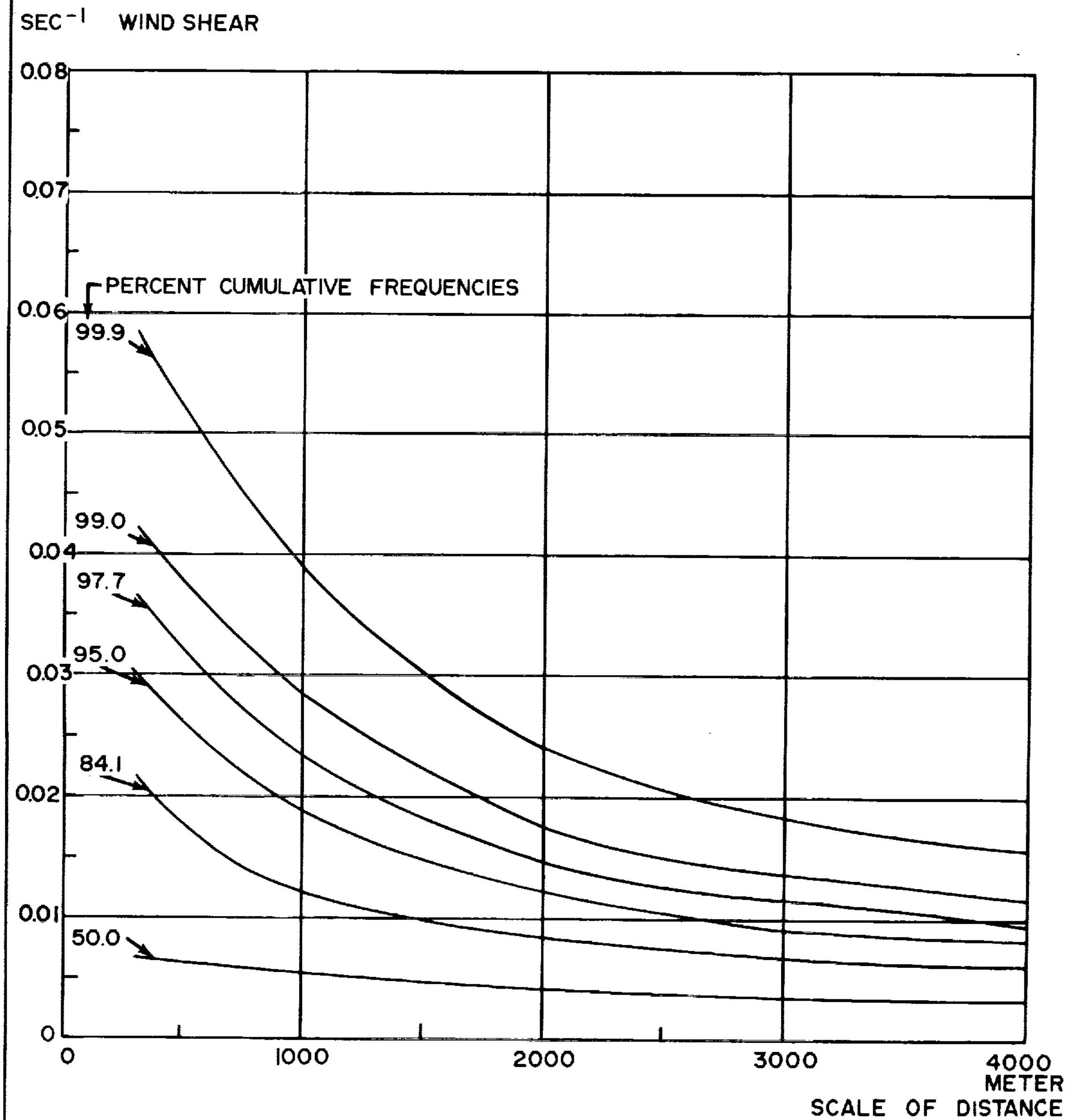
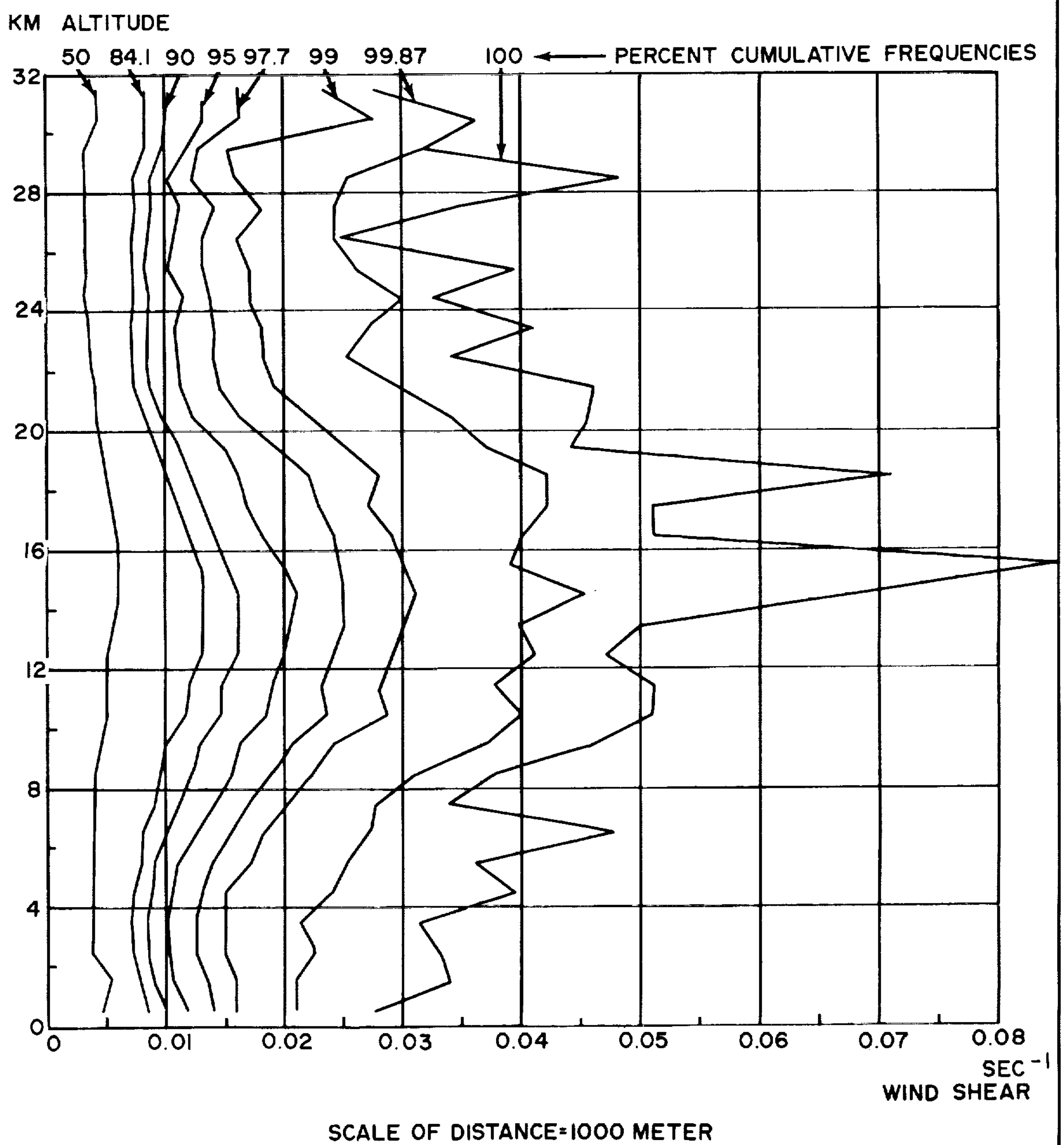
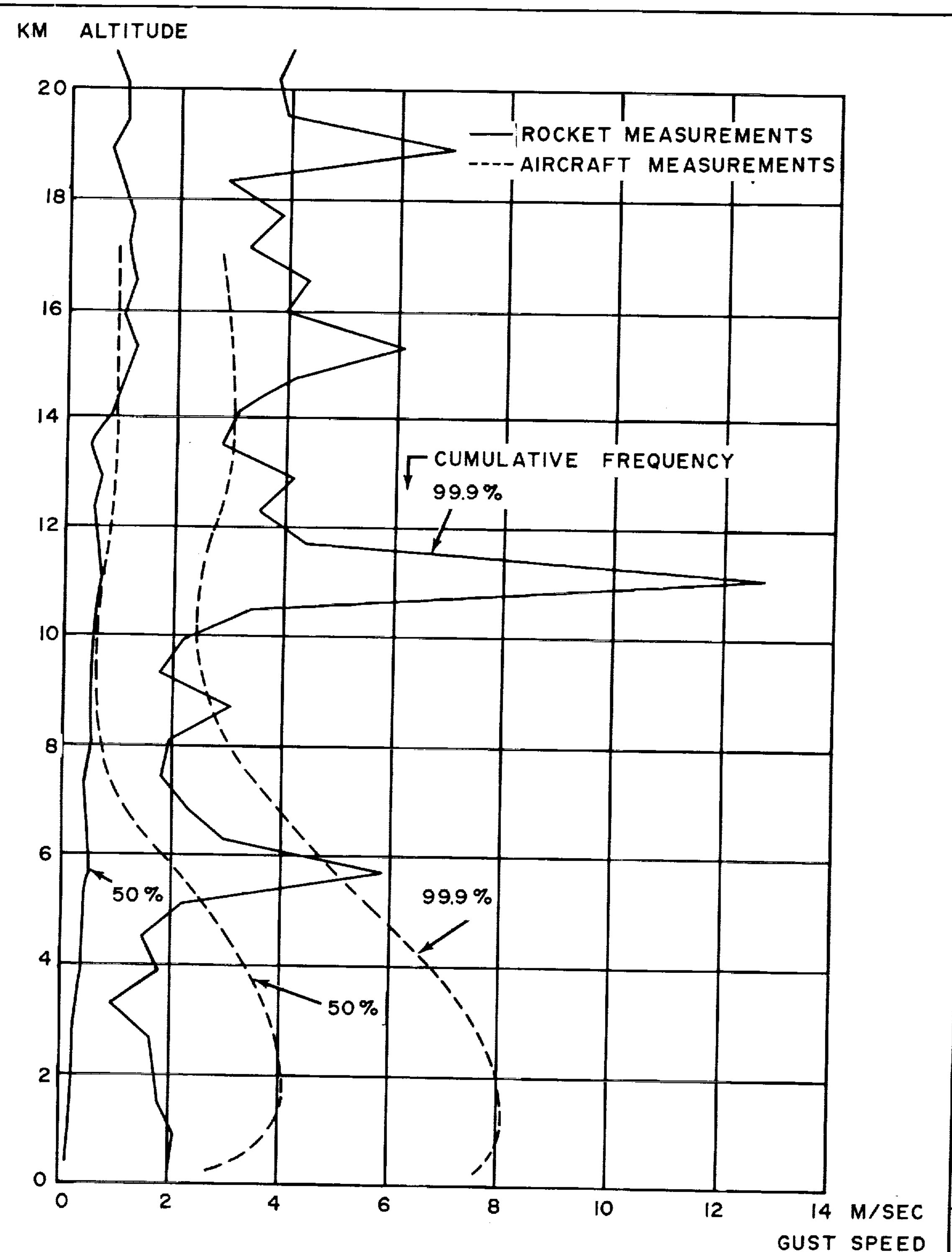


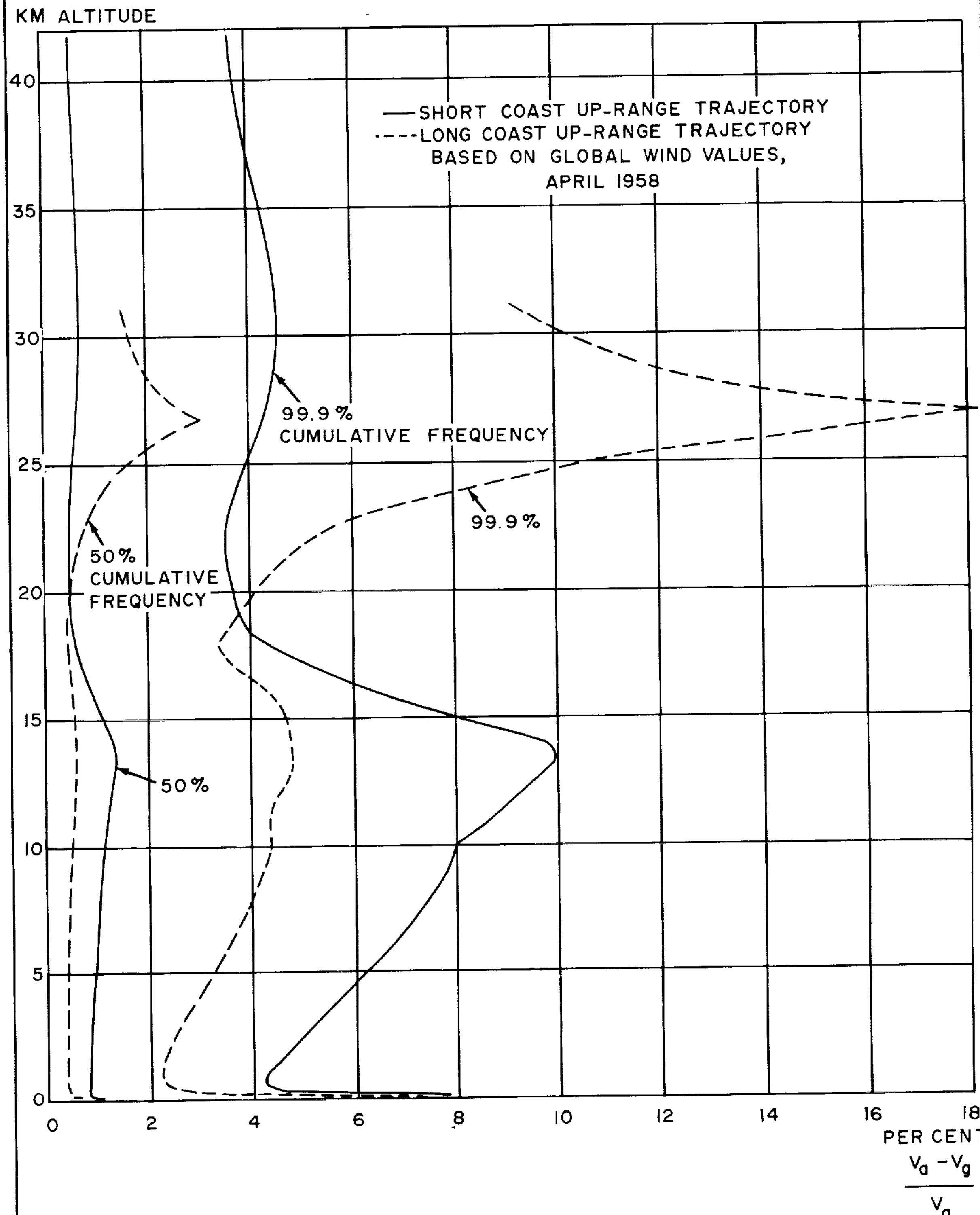

FIG. 10 EFFECT OF "SCALE OF DISTANCE" ON WIND SHEAR MAGNITUDE PATRICK AFB, FLA. – ALT: 10 . . . 14 KM




| FIG. 11 | ANNUAL WIND SHEAR (VECTOR) CUMULATIVE FREQUENCIES CAPE CANAVERAL, FLA. |
|---|---|




| FIG. 12 | GUST SPEED DISTRIBUTIONS FROM AIRCRAFT AND ROCKET MEASUREMENTS |
|---|---|




| FIG. 13 | CONTRIBUTION OF WIND SPEED TO AIRFLOW VELOCITY<br>TWO-STAGE ROCKET, 750KM BALLISTIC RANGE<br>(UP-RANGE TRAJECTORY) |
|---|---|

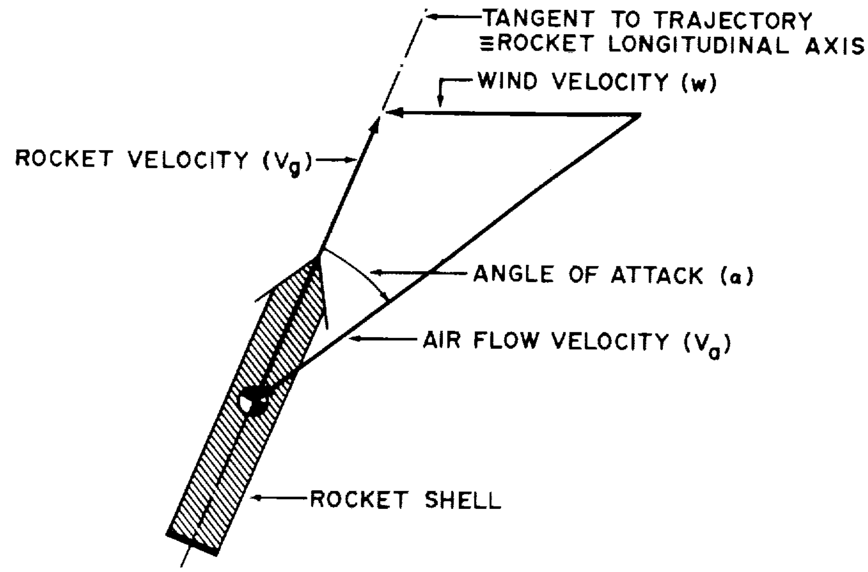



FIG. 14 ANGLE OF ATTACK IN VELOCITY TRIANGLE (IDEALIZED)

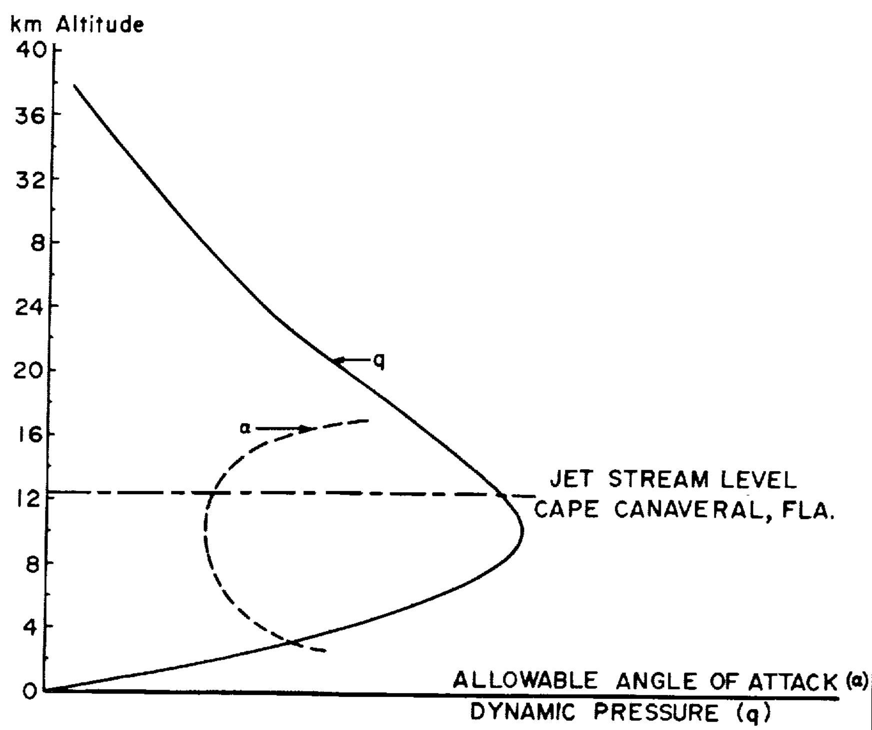
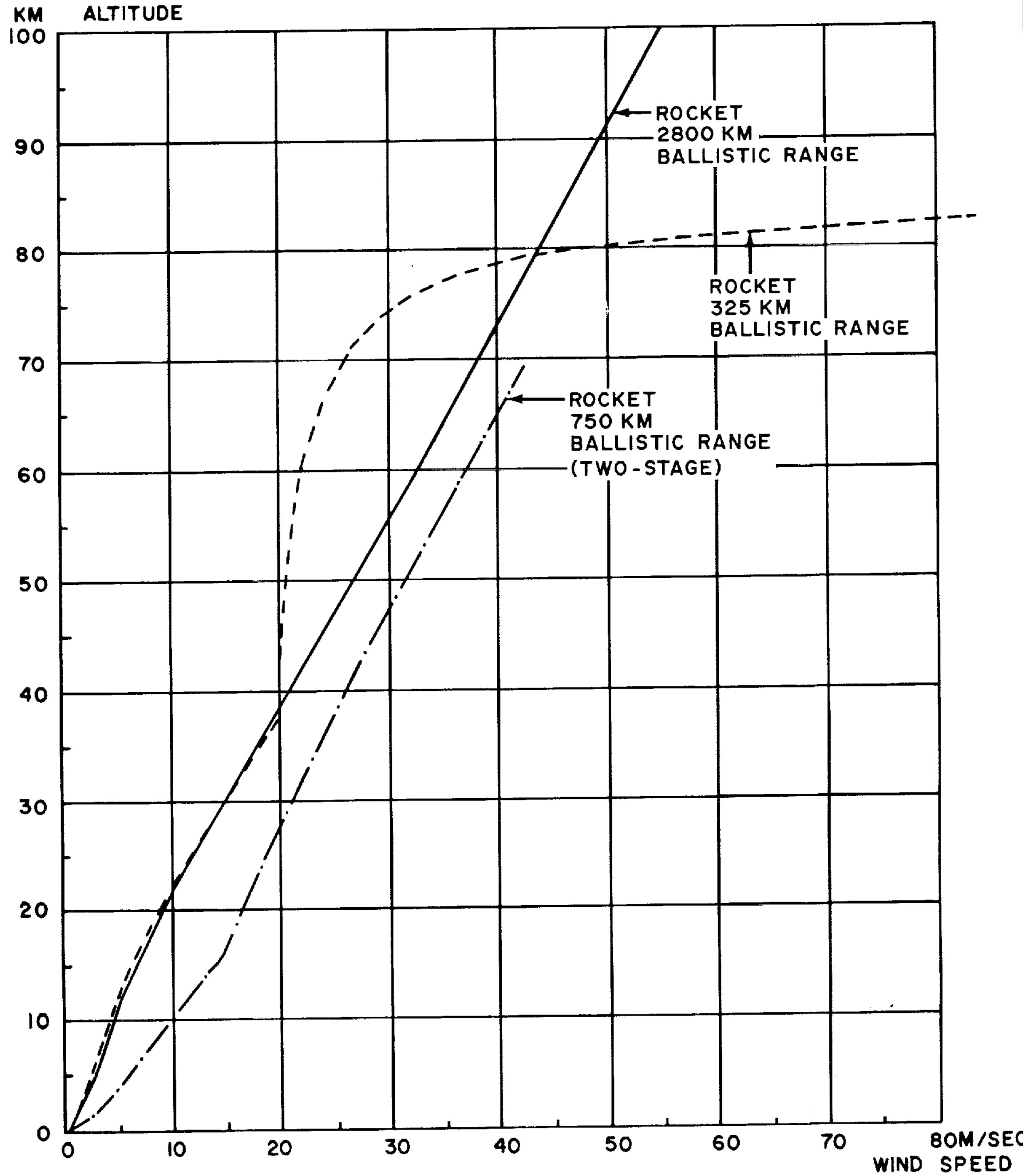
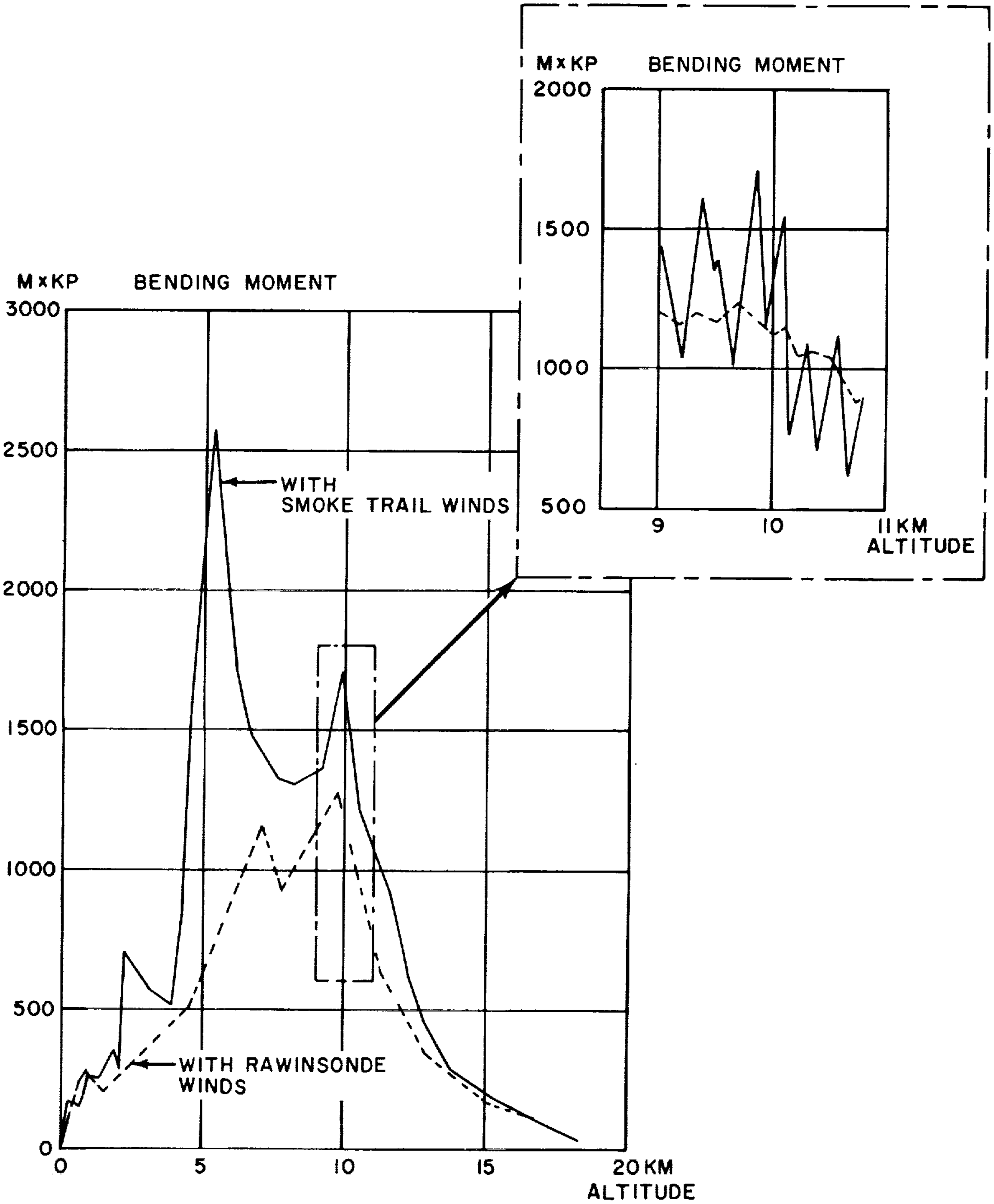



FIG. 15 ALLOWABLE ANGLE OF ATTACK AND DYNAMIC PRESSURE - ROCKET, 325 KM BALLISTIC RANGE (UPRANGE TRAJECTORY)




| FIG. 16 | WIND SPEED REQUIRED FOR BUILD-UP OF ANGLE-OF-ATTACK OF 1/2 DEGREE (UPRANGE TRAJECTORIES) |
|---|---|




| FIG. 17 | BENDING MOMENTS OF ROCKET SHELL (SCOUT) DEPENDING ON REFINEMENT OF WIND DATA (AFTER: RHODE) |
|---|---|

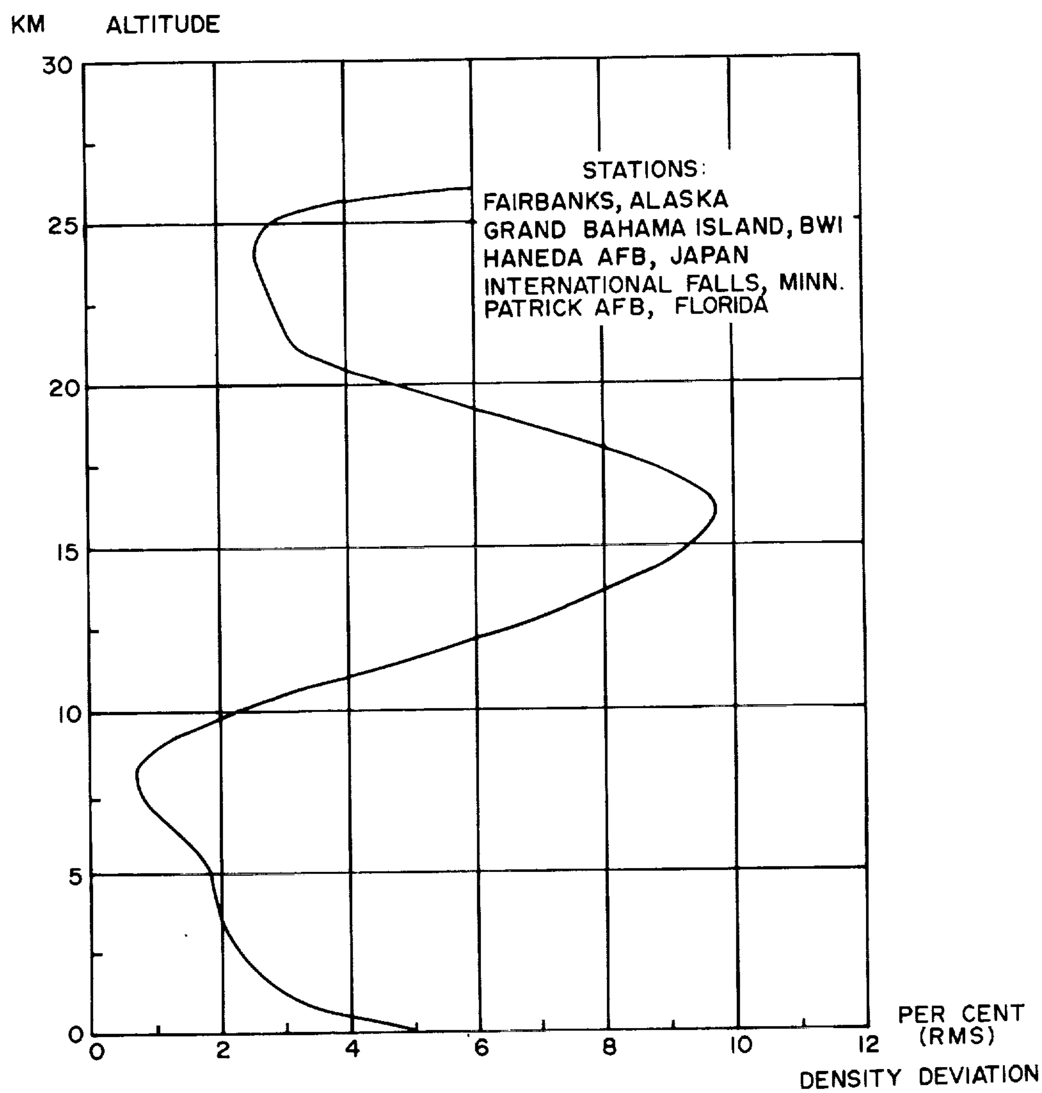
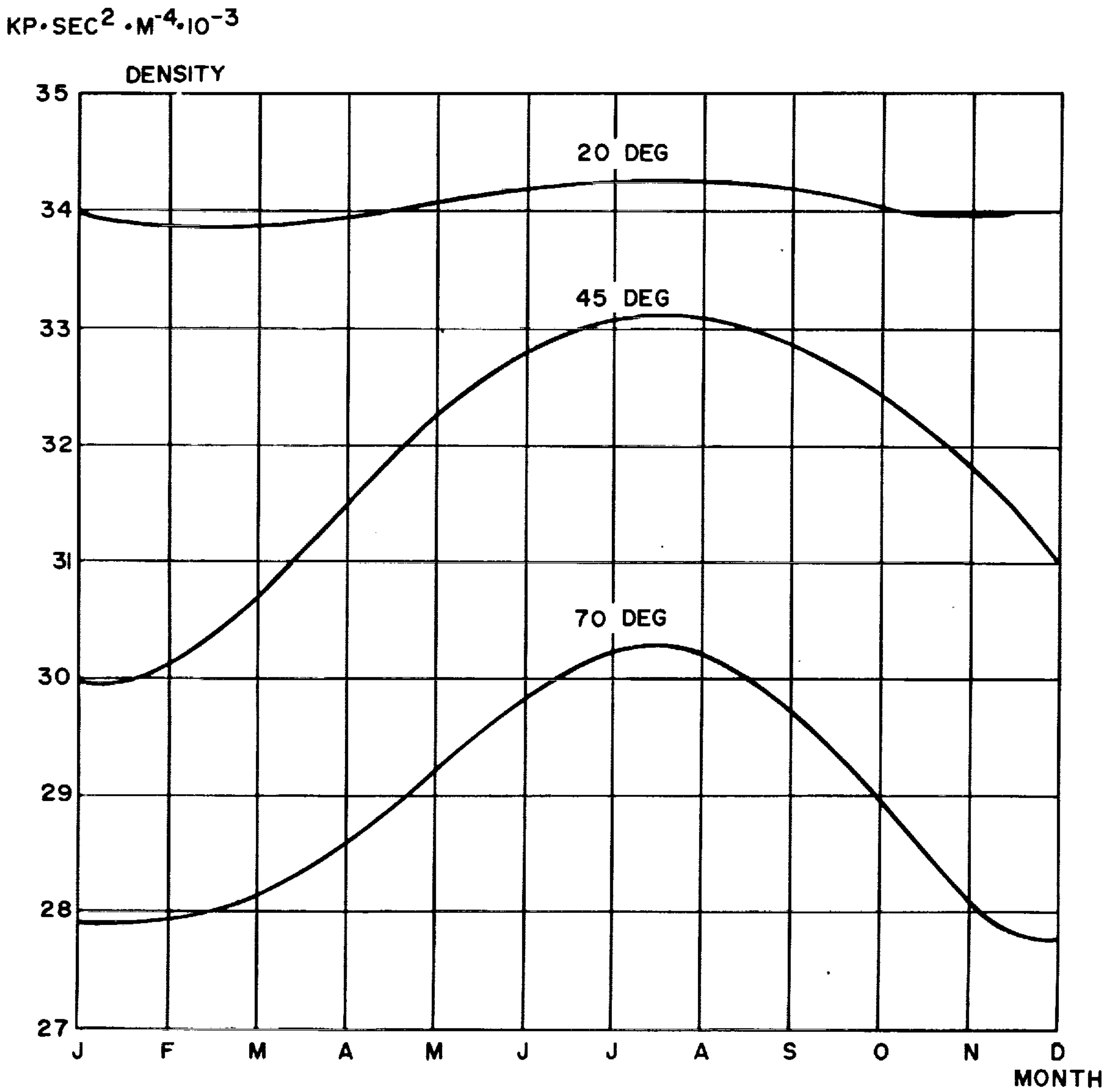



FIG. 18 — GLOBAL ANNUAL DENSITY DEVIATION FROM ARDC STANDARD ATMOSPHERE (QUADRATIC AVERAGE – FIVE STATIONS)




| FIG. 19 | SEASONAL CROSS SECTIONS OF MEAN AIR DENSITY AT THREE SELECTED LATITUDES 12 KILOMETER ALTITUDE (AFTER: ALFUTH E. A.) |
|---|---|

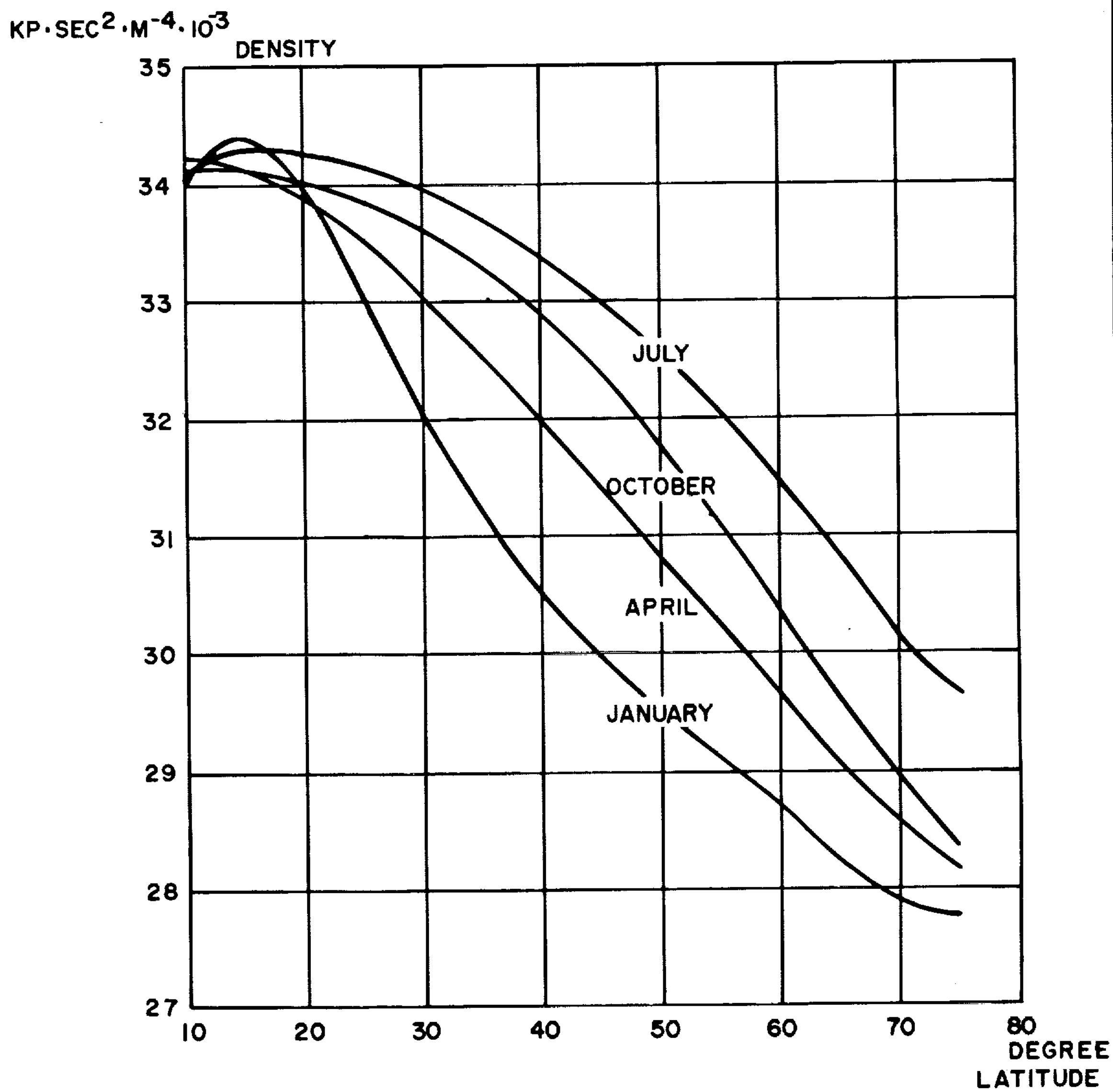



FIG. 20 LATITUDINAL CROSS SECTIONS OF MEAN AIR DENSITY FOR FOUR SELECTED MONTHS 12 KILOMETER ALTITUDE (AFTER: ALFUTH E. A.)

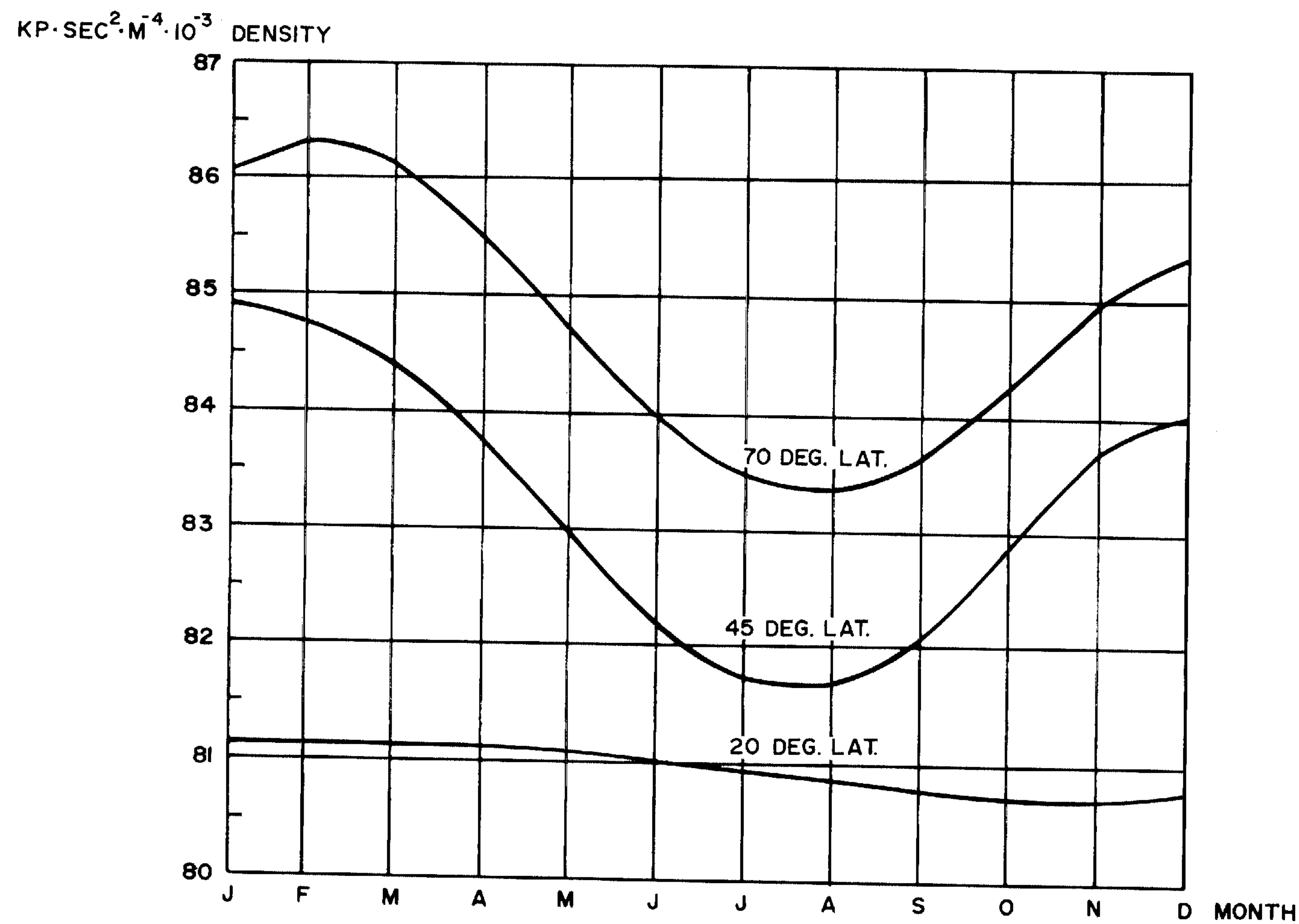



FIG.21 SEASONAL CROSS-SECTIONS OF MEAN AIR DENSITY AT THREE SELECTED LATITUDES – 4 KM ALTITUDE (AFTER: ALFUTH E. A.)

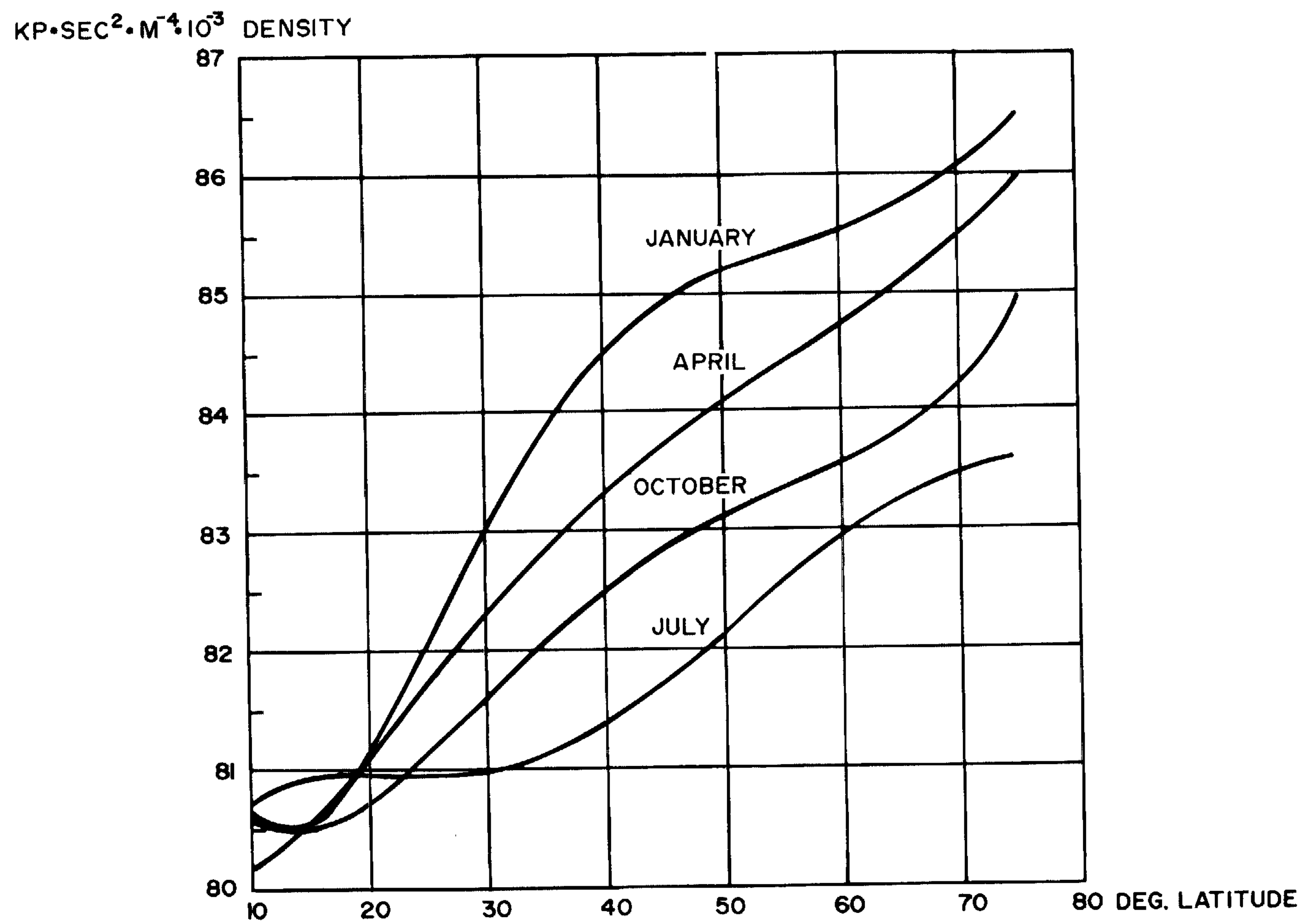
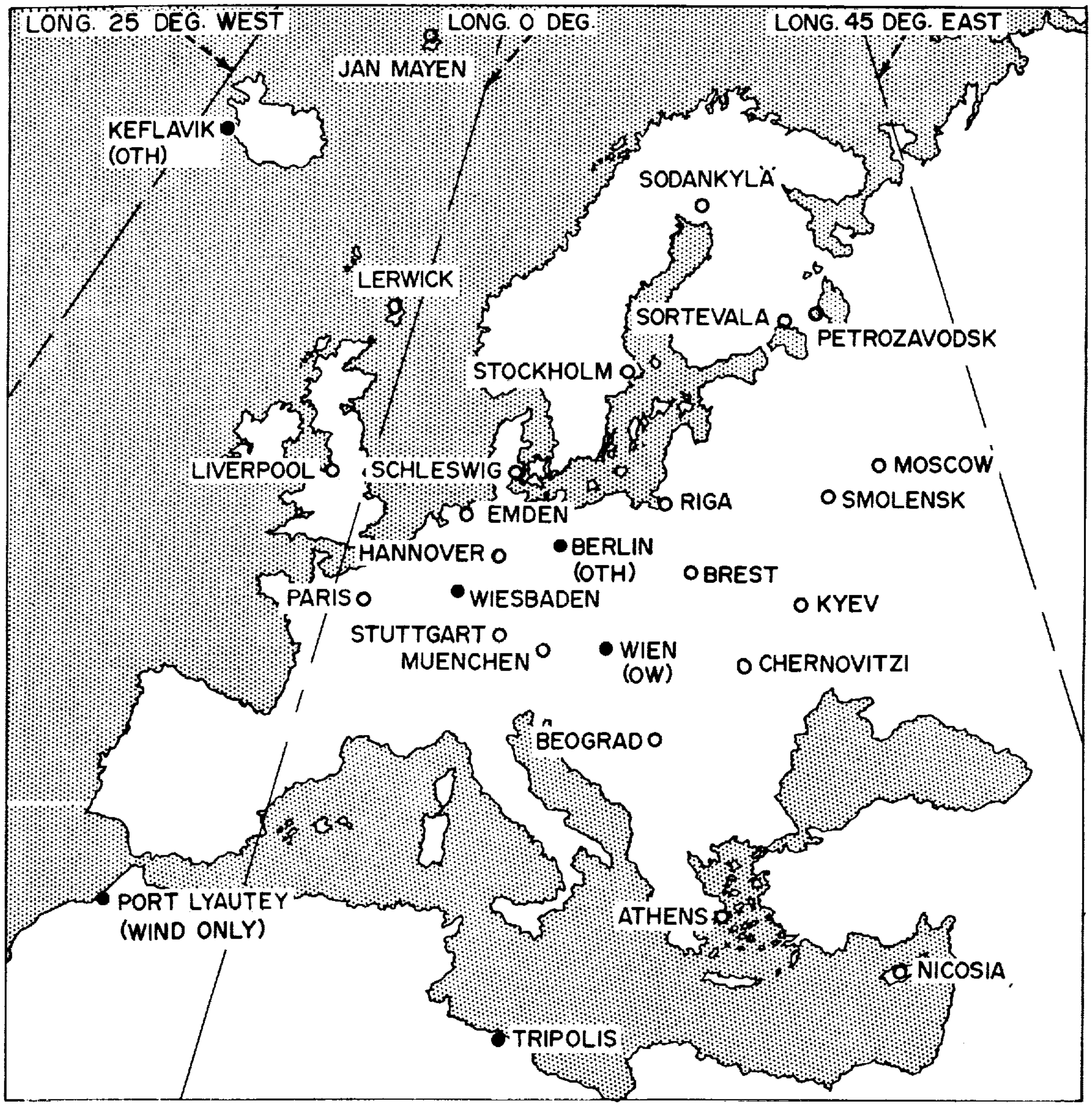


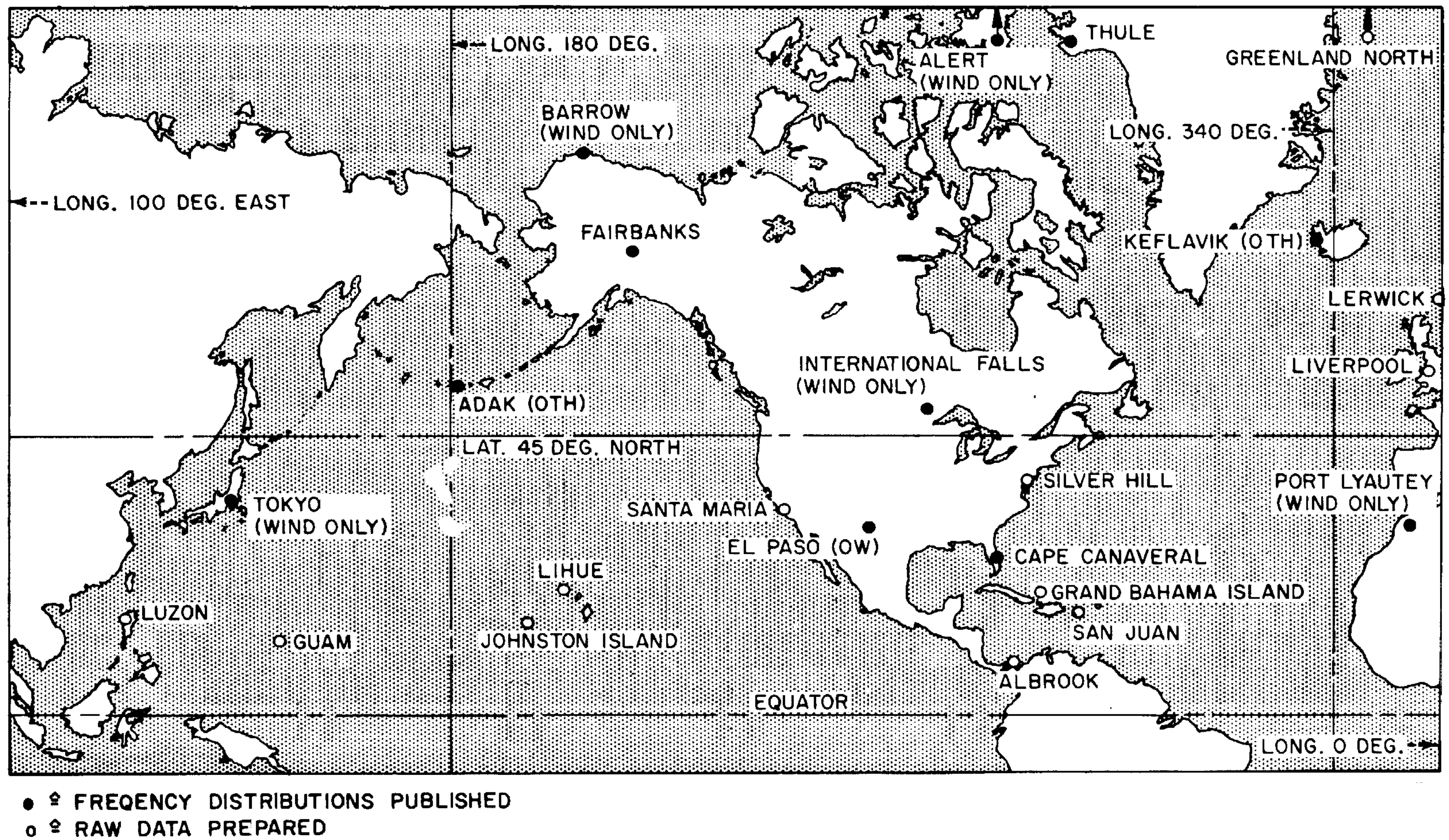

FIG. 22. LATITUDINAL CROSS SECTIONS OF MEAN AIR DENSITY FOR FOUR SELECTED MONTHS – 4 KM ALTITUDE (AFTER: ALFUTH E. A.)



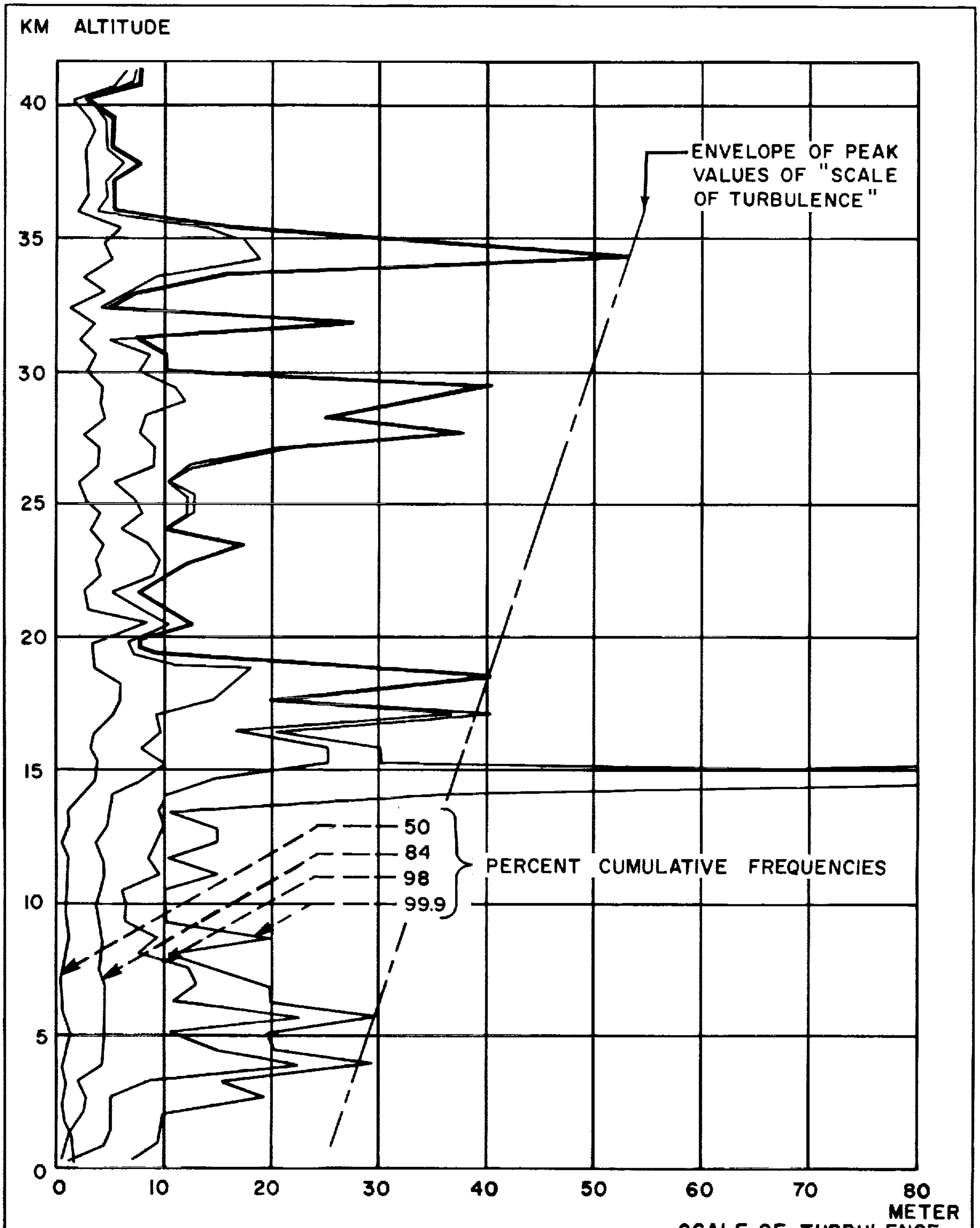

● ≙ FREQUENCY DISTRIBUTIONS PUBLISHED

○ ≙ RAW DATA PREPARED

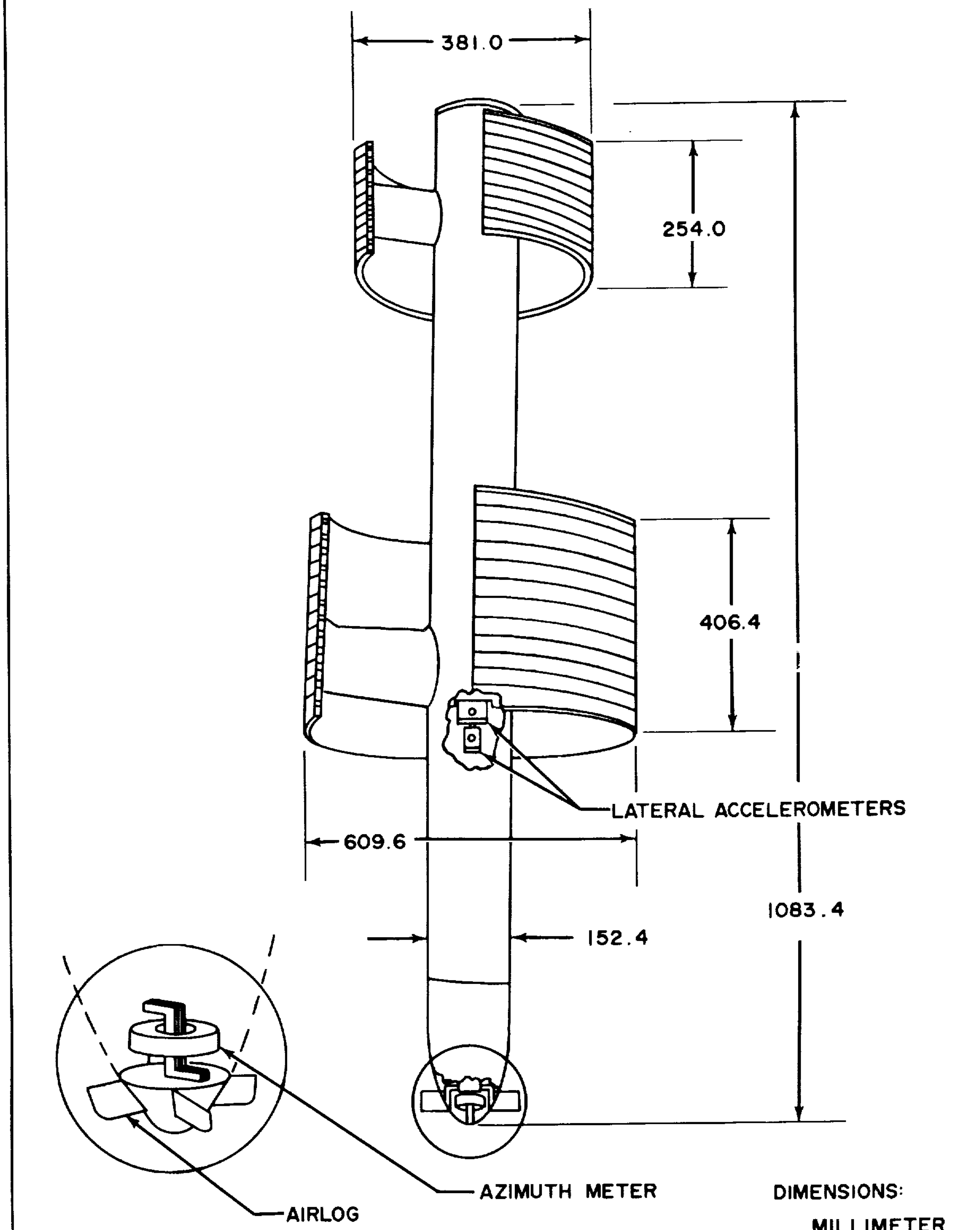
| FIG. 23 | STATIONS OF AMC CLIMATOLOGICAL RINGBROOK<br>EUROPE AND NORTH AFRICA<br>STATUS: 1 SEPTEMBER 1962 |
|---|---|



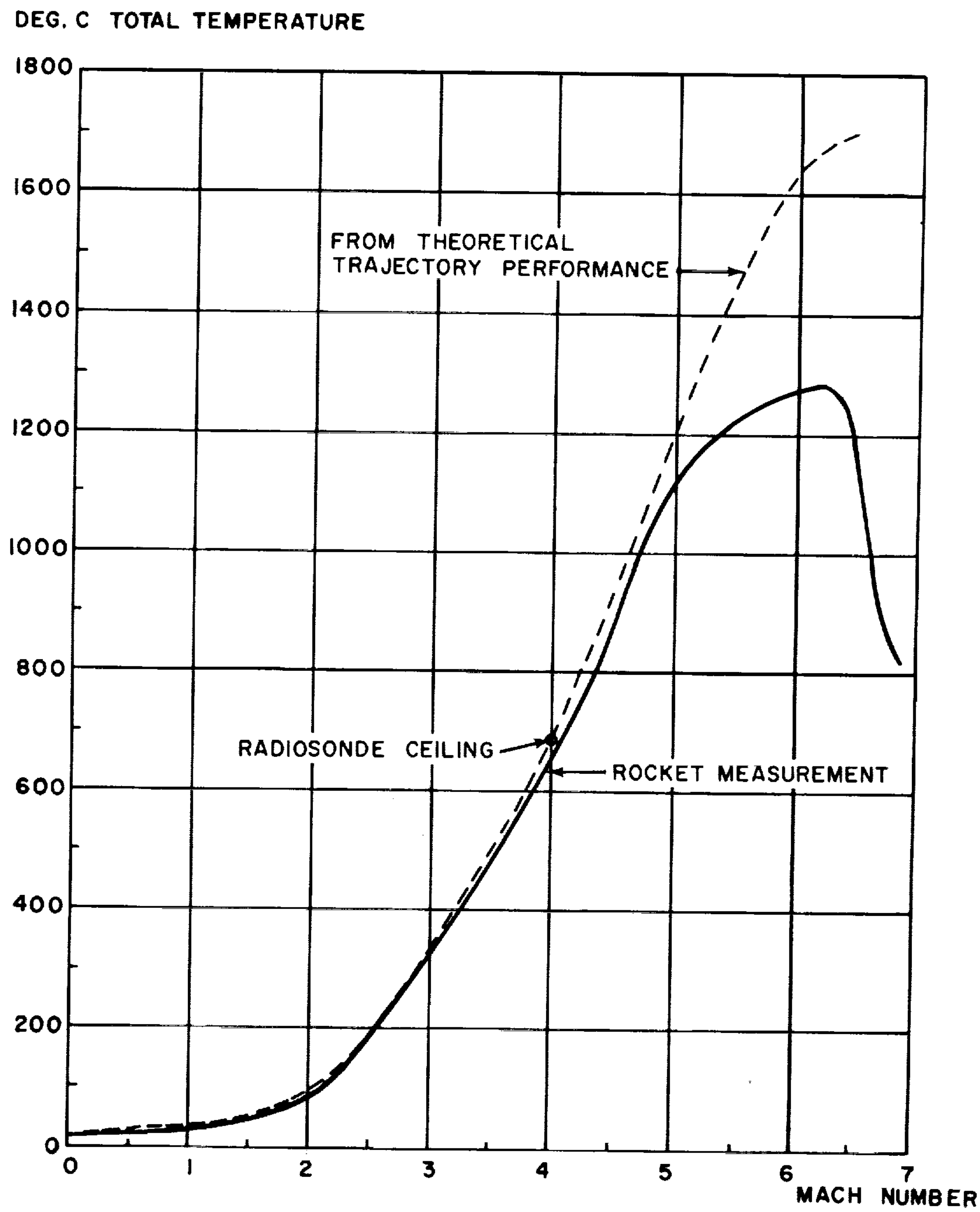

| FIG. 24 | STATIONS OF AMC CLIMATOLOGICAL RINGBOOK<br>NORTH AMERICA AND FAR EAST<br>STATUS: 1 SEPTEMBER 1962 |
|---|---|



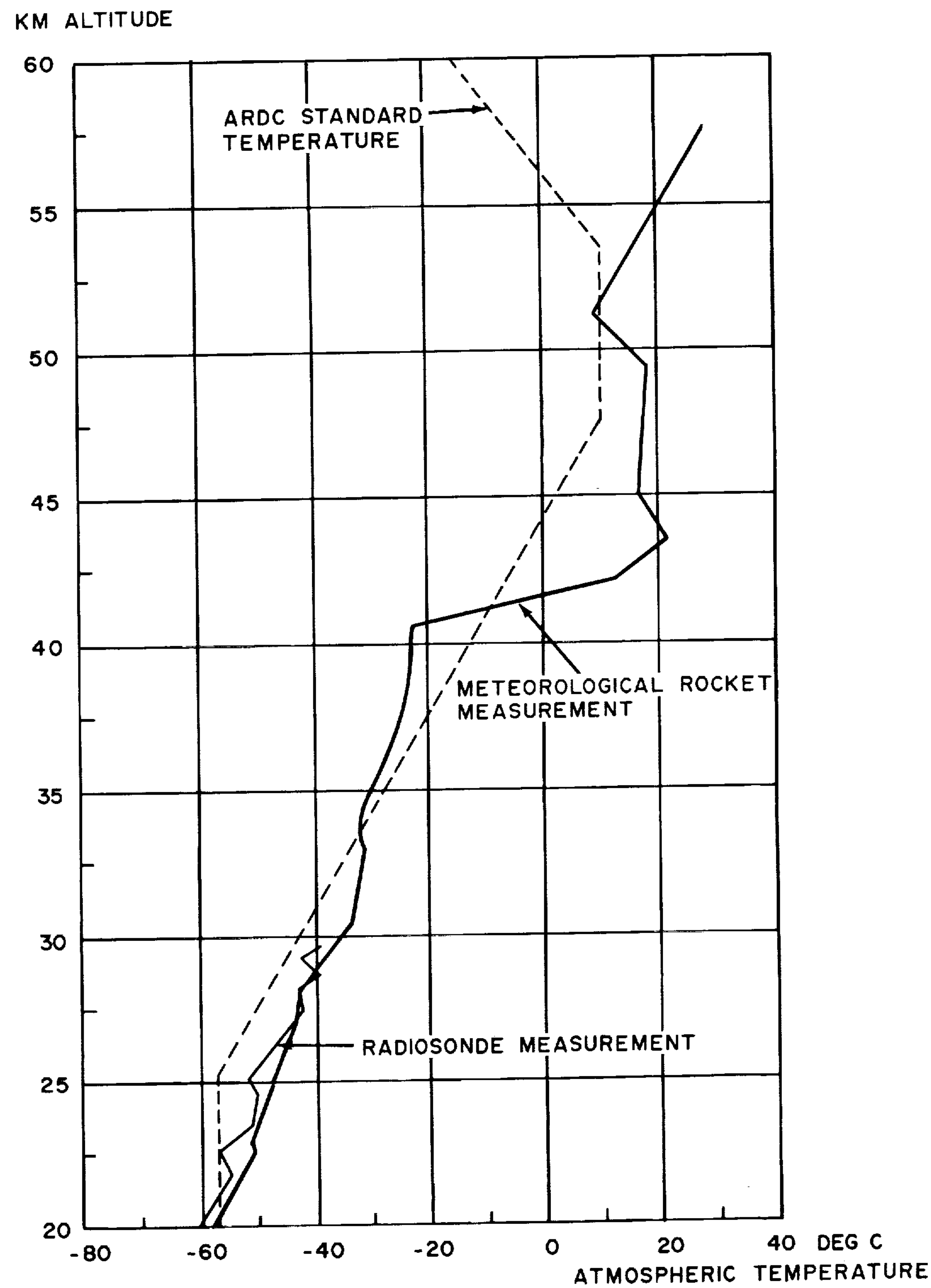

| FIG. 25 | SCALE OF TURBULENCE ("MIXING LENGTH") CUMULATIVE FREQUENCIES ROCKET MEASUREMENTS ABOVE CAPE CANAVERAL, FLA. |
|---|---|




| FIG. 26 | WIND SHEAR DROPSONDE |
|---|---|




| | |
|---|---|
| FIG. 27 | TOTAL TEMPERATURE ROCKET MEASUREMENT (ROSEMOUNT GAGE) |




| FIG. 28 | ATMOSPHERIC TEMPERATURE MEASUREMENT WITH METEOROLOGICAL ROCKET (ARCAS) |
|---|---|

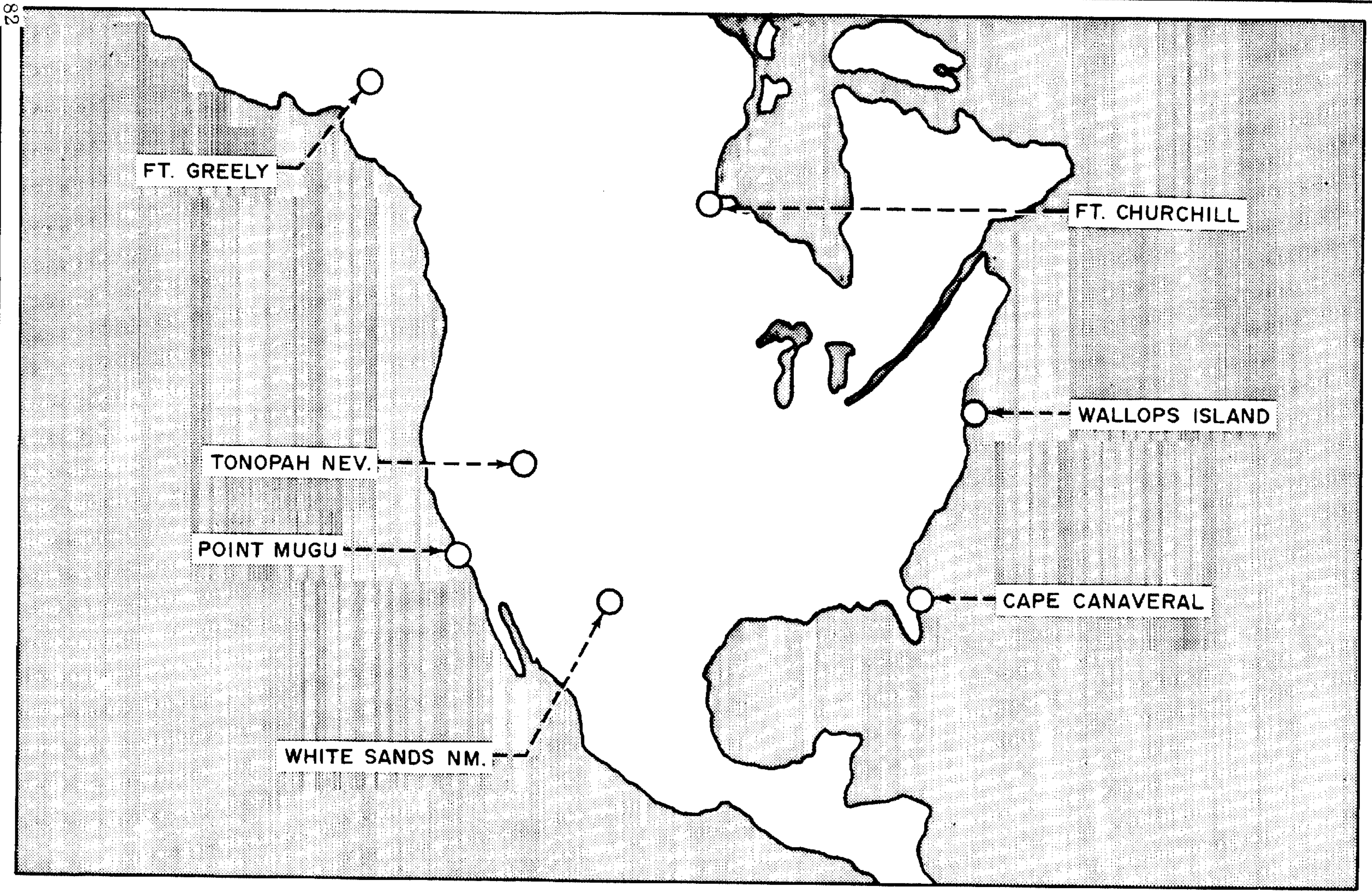
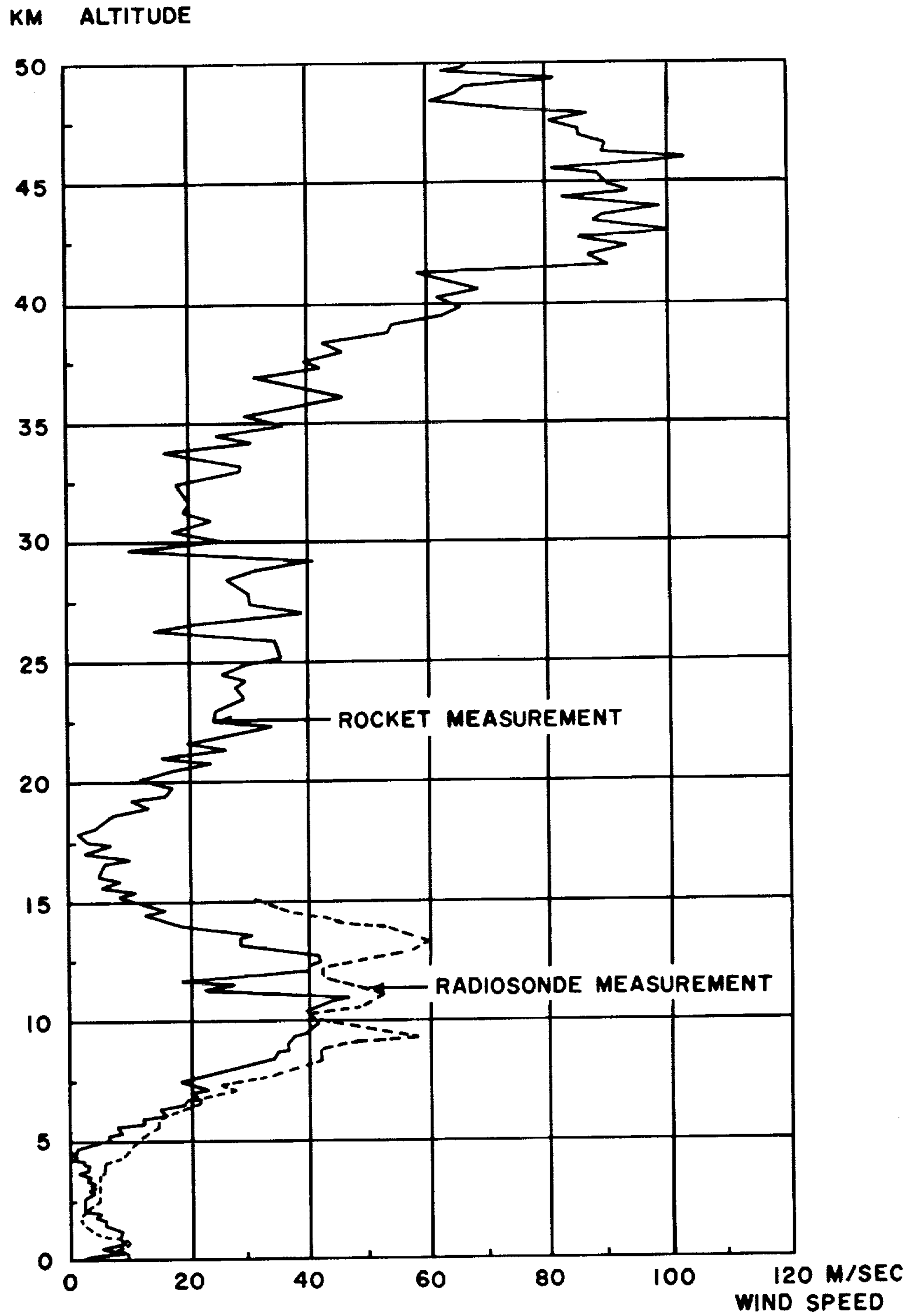
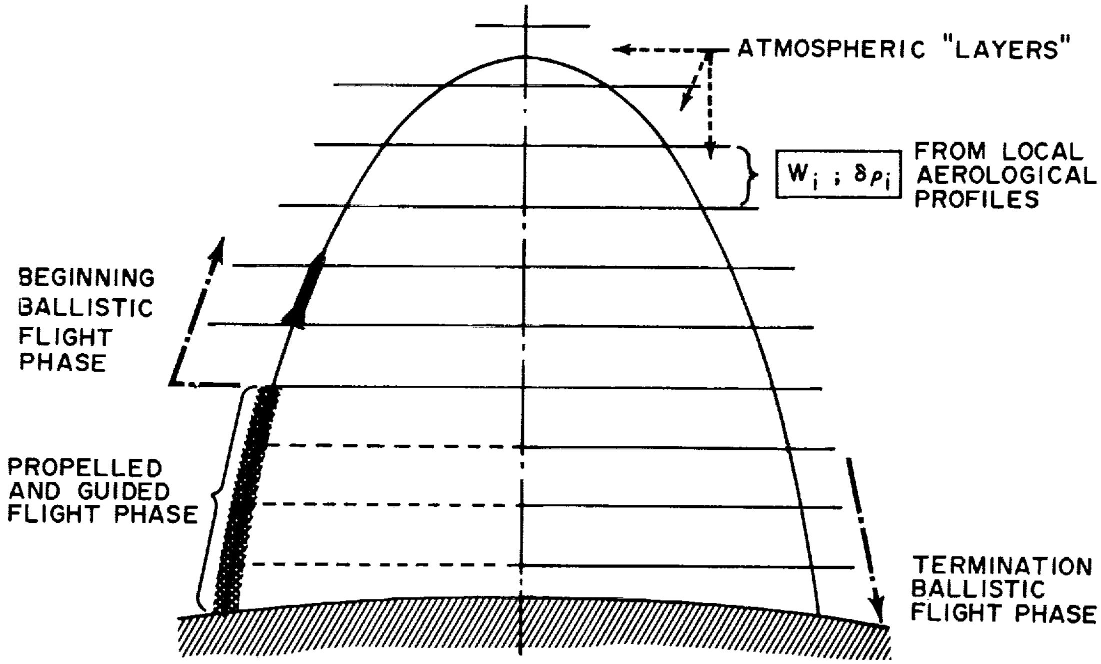



FIG. 29 METEOROLOGICAL ROCKET NETWORK FOR SYNOPTIC STRATOSPHERIC MEASUREMENTS




| | |
|---|---|
| FIG. 30 | "THREE MAXIMUM LAYER" WIND SPEED PROFILE-CAPE CANAVERAL, FLA. 9 FEBRUARY 1955 |




RANGE DISPLACEMENT DUE TO WIND: (PER ATMOSPHERIC LAYER)

$$\boxed{\Delta R_W = \frac{\partial R}{\partial W} \cdot W}$$

RANGE DISPLACEMENT DUE TO DENSITY VARIATION: (PER ATMOSPHERIC LAYER)

$$\boxed{\Delta R_\rho = \frac{\partial R}{\partial (\delta\rho)} \cdot \delta\rho}$$

TOTAL RANGE DISPLACEMENT: (FOR ALL ATMOSPHERIC LAYERS)

$$\Sigma \Delta R = \sum_i \left(\frac{\partial R}{\partial W}\right)_i \cdot W_{Ri} + \sum_i \left(\frac{\partial R}{\partial (\delta\rho)}\right)_i \cdot \delta\rho_i$$

TOTAL CROSS RANGE DISPLACEMENT: (FOR ALL ATMOSPHERIC LAYERS)

$$\Sigma \Delta C = \sum_i \left(\frac{\partial C}{\partial W}\right)_i \cdot W_{Ci} + \sum_i \left(\frac{\partial C}{\partial (\delta\rho)}\right)_i \cdot \delta\rho_i$$

$\delta\rho$ ≙ DENSITY VARIATION FROM ARDC STANDARD DENSITY PROFILE

$\frac{\partial R}{\partial W}$ ≙ BALLISTIC SENSITIVITY OF BODY DUE TO WIND

$\frac{\partial R}{\partial (\delta\rho)}$ ≙ BALLISTIC SENSITIVITY OF BODY DUE TO DENSITY DEVIATIONS

$\Delta C$ ≙ CROSS RANGE DISPLACEMENT OF BODY

$\Delta R$ ≙ RANGE DISPLACEMENT OF BODY

C ≙ CROSS RANGE

i ≙ NUMBER OF ATMOSPHERIC LAYER

R ≙ RANGE

W ≙ WIND SPEED

$W_C$ ≙ WIND COMPONENT IN CROSS RANGE DIRECTION

$W_R$ ≙ WIND COMPONENT IN RANGE DIRECTION

| | |
|---|---|
| FIG. 31 | RANGE AND CROSS RANGE DISPLACEMENTS OF BALLISTIC TRAJECTORY DUE TO WIND AND DENSITY VARIATIONS |

## VI. REFERENCES


1. REISIG, G., 1952: "Characteristic Quantities of the Wind Field Above White Sands Proving Ground, N. M.", Ordnance Missile Laboratories, Guided Missile Development Division, Aeroballistics Memorandum No. 39 (15 April 1952).

2. ALFUTH, W., AND SMITH, O., 1959: "Treatment and Statistical Evaluation for Thermodynamic Atmospheric Quantities in Climatology", Army Ballistic Missile Agency Report No. DA-TM-106-59.

3. REITER, E., 1958: "The Layer of Maximum Wind", Journal of Meteorology 15 (1958) 27.

4. ROESSGER, E., AND RAENICKE, G., 1962: "Die physikalisch-meteorologischen Grundlagen der barometrischen Hoehenmessung", Zeitschrift fuer Flugwissenschaften 10 (1962) 1.

5. ESSENWANGER, O., 1961: "Analysis of Atmospheric Turbulence from Missile Flight Wind Measurements", Army Ordnance Missile Command Report No. RR-TR-61-7.

6. REISIG, G., 1958: "Global Wind Profiles for Missile Design (April 1958)", Army Ballistic Missile Agency Report No. DA-TN-12-58.

7. SMITH, J., AND VAUGHAN, W., 1961: "Monthly and Annual Wind Distribution as a Function of Altitude for Patrick Air Force Base, Cape Canaveral, Florida", NASA TN D-610, July 1961.

8. ESSENWANGER, O., 1961: "Mean Wind Profiles by Weather Situations", Army Ordnance Missile Command Report No. RR-TR-61-34.

9. FAUST, H., 1962: "Attempt to Establish an Atmospheric Model of the Non-tropical Latitudes on the Basis of Simple Suppositions" - Project Cell Structure of the Atmosphere, Final Report (3rd year of the project) Deutscher Wetterdienst Zentralamt - Offenbach (Main), May 1962.

10. ESSENWANGER, O., 1962: "On the Mathematical Characteristics of Individual Wind Profiles", Army Missile Command Report, 1962 (to be published).

11. VAUGHAN, W., 1959: "Analysis of Discrete Atmospheric Gust Velocity Data for use in Missile Design and Performance Studies", Army Ballistic Missile Agency Report No. DA-TR-68-59.

12. GEISSLER, E., 1960: "Probleme der Richtungsstabilisierung grosser gesteuerter Flugkoerper", Raketentechnik und Raumfahrtforschung 4 (1960) 109.

13. PRESS, H., 1957: "Atmospheric Turbulence Environment with Special Reference to Continuous Turbulence", AGARD Report 115 (North Atlantic Treaty Organization), Paris (France) 1957.

14. REISIG, G., 1956: "Instantaneous and Continuous Wind Measurements up to the Higher Stratosphere", Journal of Meteorology 13 (1956) 448.

15. RHODE, R., 1962: "The First Hundred Seconds", Astronautics 7 (1962) 14.

16. REISIG, G., AND ALFUTH, W., 1958: "Global Density Deviation Profiles Independent of Geographic Location and Season", Army Ballistic Missile Agency Report No. DA-TN-31-58.

17. LINKE, F., 1919: "Ueber die Luftdichte (On Air Density)", Beitraege zur Physik der Freien Atmosphaere 8 (1919) 194.

18. FAUST, H., 1960: "The Cell Structure of the Atmosphere", Final Report (2nd year of contract - Deutscher Wetterdienst Zentralamt - Offenbach (Main), December 1960.

19. ALFUTH, W., ALSOBROOK, A., AND DICKEY, L., 1961: "Polynomial Representation of Atmospheric Density as a Function of Geographic Latitude and Month", Army Ballistic Missile Agency Report No. RR-TM-1-61.

20. ALFUTH, W., DICKEY, L., AND ALSOBROOK, A., 1960: "An Attempt to Establish a Standard Atmospheric Density Profile Under Consideration of Its Time and Space Variations", Army Ballistic Missile Agency Report No. RR-TR-3-60.

21. ESSENWANGER, O., 1960: "Preliminary Results of Research on Density Profiles in Respect to Mathematical Representation and Classification by Weather Type", Army Ordnance Missile Command Report No. RR-TN-61-6.

22. ROTH, E., AND SAENGER, R., 1962: "Ueber den Einfluss der Temperatur auf die Flugbahn eines Geschosses", Zeitschrift fuer Angewandte Mathematik und Physik (ZAMP)13 (1962) 175.

23. VAUGHAN, W., 1959: "Distribution of Hydrometeors with Altitude for Missile Design and Performance Studies", Army Ballistic Missile Agency Report No. DA-TM-138-59.

24. ESSENWANGER, O., BRADFORD, R., AND VAUGHAN, W., 1961: "On Verification of Upper-Air Winds by Vertical Shear and Extremes", Monthly Weather Review 89 (1961) 197.

25. ALFUTH, W., VAUGHAN, W., AND SMITH, O., 1958: "Statistical Evaluation of Winds Aloft Data (Preliminary)", Army Ballistic Missile Agency Report No. DA-TM-76-58.

26. REISIG, G., 1959: "Resumé of Missile Measured Winds at Cape Canaveral, Florida", Army Ballistic Missile Agency Report No. DA-TR-3-59.

27. GOETZ, O., 1962: "Preliminary Studies of the Impact of Hydrometeors upon Missiles in Flight", Army Ordnance Missile Command Report No. RR-TM-62-2.

28. ENGEL, O., 1958: "Fragmentation of Water Drops in the Zone Behind an Air Shock", Journal of Research National Bureau of Standards 60 (1958) 245.

29. SCHAAF, S., 1956: "Rarefied Gas Dynamics", Applied Mechanics Review 9 (1956) 413.

30. STALDER, J., GOODWIN, G., AND GREAGER, M., 1952: "Heat Transfer to Bodies in a High-Speed Rarefied-Gas Stream", NACA Report 1093, Moffett Field, California, 1952.

31. AUFM KAMPE, H. -J., 1960: "The Meteorological Rocket Network", Weatherwise 13 (1960) 192.

32. FAUST, H., 1962: "The Scientific Necessity for a Rocket Network in Europe", Journal British Interplanetary Society 18 (1962) 306.

33. LENHARD, R., 1959: "Meteorological Accuracies in Missile Testing", Journal of Meteorology 16 (1959) 447.

34. REISIG, G., 1960: "The Measurement of the Atmospheric Ambient Temperature for Missile Flight Analysis, Particularly at the Atlantic Missile Range", Army Ballistic Missile Agency Report No. RR-TR-2-60.

# VII. BIBLIOGRAPHY

1. Alfuth, W., Alsobrook, A., & Dickey, L., 1961: "Polynomial Representation of Atmospheric Density as a Function of Geographic Latitude and Month", Army Ballistic Missile Agency Report No. RR-TM-1-61.

2. Alfuth, W., Dickey, L., & Alsobrook, A., 1960: "An Attempt to Establish a Standard Atmospheric Density Profile Under Consideration of its Time and Space Variations", Army Ballistic Missile Agency Report No. RR-TR-3-60.

3. Alfuth, W., & Smith, O., 1959: "Treatment and Statistical Evaluation for Thermodynamic Atmospheric Quantities in Climatology", Army Ballistic Missile Agency Report No. DA-TM-106-59.

4. Alfuth, W., Vaughan, W., & Smith, O., 1958: "Statistical Evaluation of Winds Aloft Data (Preliminary)", Army Ballistic Missile Agency Report No. DA-TM-76-58.

5. Aufm Kampe, H.-J., 1960: "The Meteorological Rocket Network", Weatherwise 13 (1960) 192.

6. Engel, O., 1958: "Fragmentation of Water Drops in the Zone Behind an Air Shock", Journal of Research National Bureau of Standards 60 (1958) 245.

7. Essenwanger, O., 1960: "Preliminary Results of Research on Density Profiles in Respect to Mathematical Representation and Classification by Weather Type", Army Ordnance Missile Command Report No. RR-TN-61-6.

8. Essenwanger, O., 1961: "Analysis of Atmospheric Turbulence from Missile Flight Wind Measurements", Army Ordnance Missile Command Report No. RR-TR-61-7.

9. Essenwanger, O., 1961: "Mean Wind Profiles by Weather Situations", Army Ordnance Missile Command Report No. RR-TR-61-34.

10. Essenwanger, O., 1962: "On the Mathematical Characteristics of Individual Wind Profiles", Army Missile Command Report, 1962 (to be published).

11. Essenwanger, O., Bradford, R., & Vaughan, W., 1961: "On Verification of Upper-Air Winds by Vertical Shear and Extremes", Monthly Weather Review 89 (1951) 197.

12. Faust, H., 1960: "The Cell Structure of the Atmosphere", Final Report (2d year of contract) - Deutscher Wetterdienst Zentralamt - Offenbach (Main), December 1690.

13. Faust, H., 1962: "Attempt to Establish an Atmospheric Model of the Non-tropical Latitudes on the Basis of Simple Suppositions" - Project Cell Structure of the Atmosphere, Final Report (3d year of the project) - Deutscher Wetterdienst Zentralamt - Offenbach (Main), May 1962.

14. Faust, H., 1962: "The Scientific Necessity for a Rocket Network in Europe", Journal British Interplanetary Society 18 (1962) 306.

15. Geissler, E., 1960: "Probleme der Richtungsstabilisierung grosser gesteuerter Flugkoerper", Raketentechnik und Raumfahrtforschung 4 (1960) 109.

16. Goetz, O., 1962: "Preliminary Studies of the Impact of Hydrometeors upon Missiles in Flight", Army Ordnance Missile Command Report No. RR-TM-62-2.

17. Lenhard, R., 1959: "Meteorological Accuracies in Missile Testing", Journal of Meteorology 16 (1959) 447.

18. Linke, F., 1919: "Ueber die Luftdichte (On Air Density)", Beitraege zur Physik der Freien Atmosphaere 8 (1919) 194.

19. Press, H., 1957: "Atmospheric Turbulence Environment with Special Reference to Continuous Turbulence", AGARD Report 115 (North Atlantic Treaty Organization), Paris (France) 1957.

20. Reisig, G., 1952: "Characteristic Quantities of the Wind Field Above White Sands Proving Ground, N. M.", Ordnance Missile Laboratories, Guided Missile Development Division, Aeroballistics Memorandum No. 39 (15 April 1952).

21. Reisig, G., 1956: "Instantaneous and Continuous Wind Measurements up to the Higher Stratosphere", Journal of Meteorology 13 (1956) 448.

22. Reisig, G., 1958: "Global Wind Profiles for Missile Design (April 1958)", Army Ballistic Missile Agency Report No. DA-TN-12-58.

23. Reisig, G., 1959: "Resumé of Missile Measured Winds at Cape Canaveral, Florida", Army Ballistic Missile Agency Report No. DA-TR-3-59.

24. Reisig, G., 1960: "The Measurement of the Atmospheric Ambient Temperature for Missile Flight Analysis, Particularly at the Atlantic Missile Range", Army Ballistic Missile Agency Report No. RR-TR-2-60.

25. Reisig, G., & Alfuth, W., 1958: "Global Density Deviation Profiles Independent of Geographic Location and Season", Army Ballistic Missile Agency Report No. DA-TN-31-58.

26. Reiter, E., 1958: "The Layer of Maximum Wind", Journal of Meteorology 15 (1958) 27.

27. Rhode, R, 1962: "The First Hundred Seconds", Astronautics 7 (1962) 14.

28. Roessger, E., & Raenicke, G., 1962: "Die physikalisch-meteorologischen Grundlagen der barometrischen Hoehenmessung", Zeitschrift fuer Flugwissenschaften 10 (1952) 1.

29. Roth, E., Saenger, R., 1962: "Ueber den Einfluss der Temperatur auf die Flugbahn eines Geschosses", Zeitschrift fuer Angewandte Mathematik und Physik (AMP) 13 (1962) 175.

30. Schaaf, S., 1956: "Rarefied Gas Dynamics", Applied Mechanics Review 9 (1956) 413.

31. Smith, J., & Vaughan, W., 1961: "Monthly and Annual Wind Distribution as a Function of Altitude for Patrick Air Force Base, Cape Canaveral, Florida", NASA TN D-610, July 1961.

32. Stalder, J., Goodwin, G., & Greager, M., 1952: "Heat Transfer to Bodies in a High-Speed Rarefied-Gas Stream", NACA Report 1093, Moffett Field, California, 1952.

33. Vaughan, W., 1959: "Analysis of Discrete Atmospheric Gust Velocity Data for use in Missile Design and Performance Studies", Army Ballistic Missile Agency Report No. DA-TR-68-59.

34. Vaughan, W., 1959: "Distribution of Hydrometeors with Altitude for Missile Design and Performance Studies", Army Ballistic Missile Agency Report No. DA-TM-138-59.



NASA-Langley, 1963 M750